AN
ESSAY
FOR THE
DISCOVERY
OF THE
LONGITUDE at SEA,

By ſeveral New Methods fully and Particularly laid before the Publick.

By ISAAC HAWKINS. k

Mathemat! vol 2.

LONDON:
Printed for the Author, and Sold by R. WILKINS,
at the *King's Head* in St. *Paul's* Church-yard, and
D. JACKSON, at the *Bible* and *Three Crowns* in
the *Poultry*. 1714. [redacted]

18 Aug

[illegible]

TO THE

Right Honourable THOMAS Earl of *Pembroke* and *Montgomery*.

The Right Reverend PHILIP Lord Biſhop of *Hereford*.

The Right Reverend GEORGE Lord Biſhop of *Briſtol*.

The Right Honourable THOMAS Lord TREVOR.

The Honourable Sir THOMAS HANMER, Ba$^{rt.}$ Speaker of the Honourable HOUSE OF COMMONS.

The Speaker of the Honourable HOUSE of COMMONS.

The Honourable FRANCIS ROBERTS, *Eſq.*
JAMES STANHOPE, *Eſq.*
WILLIAM CLAYTON, *Eſq.*
WILLIAM LOWNDES, *Eſq.*

The Firſt Commiſſioner of the *Admiralty*.

The Firſt Commiſſioner of the *Navy*.

The Firſt Commiſſioner of *Trade*.

The Admirals of the *Red*, *White* and *Blue* Squadrons.

The Maſter of the *Trinity-Houſe.*

The Preſident of the *Royal-Society.*

The *Royal Aſtronomer* of *Greenwich.*

The *Savilian*, *Lucaſian* and *Plumian*, Profeſſors of the *Mathematicks* in *Oxford* and *Cambridge*,

COMMISSIONERS appointed by Act of Parliament for the Diſcovery of the *Longitude* at *Sea*, and for Examining, Trying and Judging of all Propoſals, Experiments and Improvements relating to the ſame,

Theſe Methods for Diſcovery of the Longitude *at* Sea, *are Humbly Submitted by the Author.*

THE
Epiſtle Dedicatory.

TO

JOHN WHITE,
AND
TAYLOR WHITE, } *Eſqrs.*

OF

WALDIN WELLS.

GENTLEMEN,

THE *Religious Regard due to my KING and Country, which prompts and obligeth me to be very particular and unreserved in the Publication of the following Treatiſe, will, I am aſſured, make it a more acceptable Preſent to you, than otherwiſe all the Ad-*

dreſs and Oratory of an abler Pen: For, I can truly ſay, what Cenſure I am liable to incur by attempting to Pilot our Fleets thro' the Pathleſs Ocean, or what private Advantage I may hereby Reap, is to me a Matter of leſs Concern.

I muſt own, That, notwithſtanding the Intimations you have given me, in relation to my Methods of finding the Longitude at Sea; *I am ſtill perſwaded, that the Foundation at leaſt of this great Diſcovery is herein laid; and therefore cannot, but reckon it a Duty, to run all Ventures, rather than conceal one diſtant Hint from a better Projector, who may improve it to the deſired Effect. If I may promiſe my ſelf this Succeſs in the preſent Undertaking, I devote it entirely to the Publick; Submitting the Propoſition to the truly Reverend, Honourable and Worthy, the* Commissioners *appointed by* Parliament *to Judge and Determine of this Matter: But the Theory I have deſign'd for you, as the propereſt Entertainment, I can give at your leaſure Hours, to direct your ſearching Curioſity,* *ſurprizing Judgment and penetrating Inſight into the Phænomena of Nature, and as an acknowledgment of my ſpecial Obligations, to aſſiſt you in Mathematical Studies, as far as I am able.*

The bare Expectation and Hope of ſerving Trade and Navigation thereby, is a Satisfaction; but this Satisfaction will be inexpreſſible, if my Endeavours contribute to your future Patronage of theſe Profeſſions, of which we have already the moſt encouraging Proſpect: For this End I muſt take the Liberty of a Monitor, to remonſtrate, That Heaven hath as much favoured you, as any of your Rank, within the Compaſs of my Acquaintance, with both Abilities and Advantages for the Service of Church and State. You Gentlemen have Vertue and Wiſdom ſet before you (not as many others, in ſcattered Parcels and Periods, but) in a finiſhed and uninterrupted Scene, in ample Precepts and eminent Pecedents, theſe the moſt Endearing and Attractive, from ſome of whom you derive your Beings, your Names and Bleſſings, celebrated for whatever a-

dorns the Character of an accompliſhed Gentleman, an able, faithful Patriot, and a ſincere Chriſtian: That ſuch you may fully anſwer, and be finally approved, is the fervent Prayer and Hope of

Your Zealous

London, Auguſt
18th. 1714.

humble Servant,

Jſ. Hawkins.

AN ESSAY ON THE COMMENSURATION OF THE LONGITUDE at SEA.

The INTRODUCTION.

ONE of the greateſt Demands made upon the Mathematicks, is from the Merchant, of a commodious, General and Ready Way of Meaſuring the Earth, and finding Diſtances in any Stations aſſign'd, and their reſpect or bearing one to another, in order to direct their Courſe and ſecure their Aim, in Travelling from one Part of the World to another, which is the Deſign of the enſuing Treatiſe.

To anſwer this Demand, it muſt be premis'd, That this our Reſidence, to which we are confin'd, is of a Globular Form, almoſt Round every Way, and therefore call'd the Terraqueous Globe, conſiſting of Land and Water. That it is on all ſides encompaſſed with an unnumbred Multitude of other Bodies. On all ſides, in the wide Expanſe of pure Æther, which we call the Heavens.

Now the utmoſt Limits of the Univerſe, being ſtretch'd beyond the Reach of our Sight every way, and the utmoſt bounds of our Sight being on all Sides equal, muſt appear to our Eyes in the Form of a Sphere alſo. Farther Note, That the true Diſtance of the Heavenly Bodies being too large to be eſtimated by our Senſes only, they muſt needs ſeem at an equal Diſtance, and ſo may ſerve to diverſify and diſtinguiſh the Cœleſtial Sphere. Again, The Sphere of the Heavens, anſwering to the Globe of the Earth, appearing of the ſame Form, and every Point of the one reſpecting a different Point of the other; the Cœleſtial Sphere, when it is viſible, will ſerve to diſtinguiſh and determine the correſpondent Points of the Earth; And therefore the two Sciences, Geography and Aſtronomy, which contemplate the Surface of the Heavens and the Earth diſtinctly, are mutually ſerviceable to each other, and both to our preſent Purpoſe of Meaſuring the Earth, to find the ſituation of its Parts ſeverally; that is, their Longitude and Latitude, which I am now to Conſider:

And firſt, The Names of Longitude and Latitude, are Words of various Significations: Originally, they ſignify'd no more than Length and Breadth:

Breadth; but now they are Terms of Art, and adopted into the Sciences, particularly theſe laſt mention'd. In Geography, they involve a reſpect to the Sun's Diurnal Courſe; in Aſtronomy to his Annual Courſe. Longitude is reckon'd along his Courſe, meaſuring the length of it: Latitude is reckon'd a-croſs or from its Courſe: Both theſe Reckonings fix or determine infallibly any aſſigned Point of the Surface of both Globes, and therefore of neceſſary Conſideration in Meaſuring any Length or Capacity within that Compaſs.

MEASURES are variable, and therefore muſt be ſtated or ſtinted by a certain Standard, before they can be ſerviceably apply'd; which may be done theſe two Ways:

Firſt, BY Aſſuming, Dividing, or Multiplying a known Quantity by a certain Number, thus; Suppoſe the meaſure of a Foot be aſſum'd as known, then the Meaſure of an Inch is thereby aſcertain'd, dividing the given Dimenſion by the Number 12; ſo alſo the Meaſure of a Yard, by multiplying the ſame into 3; and this ſerves both for Aſſigning and Comparing Quantities.

Second, BY Dividing or Multiplying an unknown Quantum, by a certain Number, as the Diameter of a Circle into a Thouſand Parts; or a quarter of a Circle into Two. This Way does not Meaſure Quantities abſolutely, but aſſigns the Proportion of Quantities only. This laſt Way is always uſed in Circles, whether larger or leſſer. This Note is neceſſary to be given by the Way, becauſe Meaſure is in Mathematicks, the ſame as Words in Converſation, the Signs by which we communicate Ideas.

NOW before I Enter upon the Things themſelves, here propoſed, I muſt beg the skilful Readers leave, to make my Way into the Subject by firſt Principles, in the general Method of the Sciences, for ſeveral Reaſons.

Firſt, BECAUSE it is Recommended to ſuch Perſons, among others, as may ſtand in need of theſe Helps, to give them a full View of this Undertaking, whoſe Aſſiſtance herein is by no means to be ſlighted.

Secondly, THAT this Treatiſe may be entire for their Advantage, whoſe Buſineſs or Curioſity may be confin'd within this Compaſs.

Thirdly, BECAUSE ſome Treatiſes upon theſe Preliminaries may be judg'd ſufficient Inſtructions herein, which yet convey only a confus'd Idea of Things, with regard only to their Uſe, not the Reaſon of them, or their Terms; much leſs the due Method in which Things ſhould be Handled, and which ſhould make ſuch Knowledge diſtinct, well digeſted, and readily apply'd. But, I hope, I need not much Apology for the mention of theſe few following common and obvious Principles of the Science here uſed, whoſe Object is Quantity.

QUANTITY is two-fold, Continu'd, and Diſcrete: Continu'd Quantity is Extenſion, conſiſting or conſider'd without Interruption or Separation of its Parts. Diſcrete Quantity, is Multiplicity; conſiſting of Parts really ſeparate, or mentally diſtinguiſh'd: Both of theſe are in Meaſuring deſign'd and expreſs'd by Number, the firſt by Unity, the ſecond by Plurality. Theſe two Modes of Corporeal Subſtances are convey'd by the Report of our Senſes to the Mind, and receiv'd, the firſt by ſimple Intuition, the ſecond by a complex Notion or Compoſition of Simple Ideas.

ALL Sciences Mathematical proceed upon the mutual Habitude and Combination of theſe Two, illuſtrating, meaſuring and demonſtrating each other; both of them being of Infinite Capacity and Variety. Any conceivable Portion or Variety of Extenſion may be diſtinguiſhed and noted by Multiplicity of Numbers, and any Multitude or Combination of Numbers compriſed in Unity, and repreſented by Extenſion.

EXTENSION divided and Numbers repeated are the Meaſure of each other, and therefore when we ſpeak of Meaſure, both theſe are intended, for both are of neceſſary Uſe, *i. e.* a certain determinate Extenſion once or oft apply'd.

THE Meaſure of Extenſion may be conſidered or actually directed three ſeveral Ways, and therefore Space hath three different Dimenſions, which give ſo many diſtinct extended Quantities; a Line, which hath only one Dimenſion, (*viz.*) Length; a Superficies, which has two, Length and Breadth; a Solid, which has three, Length, Breadth and Thickneſs: Each of theſe Dimenſions have their proper Terms, by which they are both bounded and divided; the Dimenſions of a Line are diſtinguiſhed and terminated by Points, thoſe of a Superficies by Lines, and of a Solid by Superficies; it is in the ſecond of theſe Quantities that our Province falls, (*viz.*) a Superficies, the Superficies of the Terreſtrial Globe, of which we are to conſider the Meaſure.

Now the Meaſure of any Quantity gives its juſt Proportion to any known Standard, by the Application of thoſe Dimenſions, or the fixing and aſſigning thoſe Terms, which diſtinguiſh its Parts; therefore the proper Meaſure of a Superficies is a Line; now, the Superficies having but two Dimenſions, the Lines which meaſure them are Applicable two Ways, and no more; therefore all other intermediate Poſitions, more or leſs concurring with theſe two different, I may ſay, contrary Poſitions, are hereby determined; and therefore theſe two are ſufficient to demonſtrate all the General Affections of the Subject under Conſideration.

Of a Surface in General; a Line meaſuring the Length of it, does contain all the poſſible Variations of Length; and a Line meaſuring the Breadth, doth contain all the poſſible Varieties of Breadth within the Compaſs of the Surface given; and therefore two ſuch Lines perpendicular to each other, are ſufficient to determine the diſpoſition of the Parts, and all the general Affections of that Surface depending thereupon. Since every Point contain'd in the Superficies, is ſituate anſwerably to one or other Point in each of thoſe two Lines, determinable by other Lines, perpendicular to the former, and paſſing thro' both the Point given, and the Points, which diſtinguiſh the Parts of Length and Breadth; and therefore if the Surface given be of an oblong quadrangular Form, one Side and an End being the Meaſure of Length and Breadth, may ſerve (as is uſual) for this Purpoſe; and therefore Maps for particular Countries, are commonly ſo bounded, and the ſituation of the Parts determin'd by Points, mark'd and numbred on the Sides and Ends, to which they anſwer, or are nearly perpendicular. Sometimes the perpendicular Lines themſelves are drawn croſs each other, at equal convenient Diſtances, but ſo as to conform to the general Properties of the Globular Surface, of which they are Segments: Thus they divide the whole into ſmall Parcels, almoſt Quadrangular, for the ready finding or noting the Situation of any Part.

THE Surface of a Globe is in like Way meaſured, and the ſituation of its Parts found or diſtinguiſh'd by Lines drawn perpendicular to each other; theſe Lines will be circular, becauſe the Surface of the Globe is entirely and every way round, and if each Line keep the ſame Direction throughout, it is manifeſt by Inſpection, that they will be compleat Circles. Now, the largeſt Line that can be drawn upon the Globe, is a Circle, having the ſame Diameter as the Globe it ſelf. This Circle divides the Globe into two equal Parts or Hemiſpheres, of which the middle Points are its Poles; then ſuppoſe that other Circles be drawn, parallel to this, at convenient equal Diſtances; and directly croſs to theſe, other Lines drawn, at the ſame Diſtances from each other, Reckon'd or Meaſur'd upon the firſt mention'd Circle, then it's evident by Inſpection, (for I muſt not ſtay, to Demonſtrate here,) that the firſt Order of Lines will gradually decreaſe in their Order from the firſt on each Side to its Poles, and the ſecond Order or Croſs-lines will be all equal to the firſt, inclining to, and interſecting each other at the Poles. Thus the whole Surface of the Globe will be conveniently Diſtinguiſh'd and Meaſur'd, for Aſſigning and Determining the Situation of all its Parts mutually. Then ſuppoſe the length of the firſt Line to be divided into any Number of Parts, the Reckoning will begin and end at the ſame Point, wherever it is aſſum'd; then the Perpendicular or Croſs-lines will ſhew to what Length in the firſt Line all the Points thro' which it paſſeth anſwer; that Length is call'd their Longitude, partly, Becauſe the Line which Meaſures it, is the longeſt that can be drawn upon the Globe, without interſecting any other of its Order; and partly, becauſe it will therefore contain the longeſt Reckoning. Now if this Line be reckon'd the Meaſure of Length, the Croſs-lines muſt then be reckon'd the Meaſure of Breadth; and for that Reaſon the Reckoning on them is call'd Latitude.

IN this Order of Principles, the Point for beginning the firſt Reckoning, may be aſſum'd at pleaſure, becauſe all Points in the firſt Line are indifferent; but for the ſecond Reckoning, there are Points enough ſufficiently diſtinguiſh'd to begin at. Now, becauſe the Poles are indifferent for this Purpoſe, the Reckoning is uſually begun at the firſt Line here deſcrib'd, and proceeds on each ſide towards the Poles; ſo that there are two Differences of Latitude, and ſince the Croſs-lines interſect each other at the Poles, the whole Meaſure of both Latitudes can be but a Semi-circle, terminating at the Poles, becauſe the Term from whence the Reckoning begins, extends itſelf quite round, at an equal Diſtance from each Pole, twice interſecting each Croſs-circle, and therefore each Latitude cannot exceed a Quadrant or quarter of a Circle.

AFTER this Manner the Terraqueous Globe may be divided, for the more convenient Diſtinguiſhing and deſcribing the Situation of its Parts, and the ſolving all Problems depending hereupon. But then the Queſtion will be, How theſe ſeveral

Circles may be diſcern'd upon the Globe of the Earth? In anſwer to this; Nature has Immutably fix'd, and ſenſibly diſcover'd two oppoſite Points, by which all the reſt may be determin'd; thoſe are the two Poles, upon which the Globe Turns, the North and South Pole. Then, at an equal Diſtance betwixt them, a Circle is imagined to paſs, which is called the Equator, and ſerves as the Meaſure of Longitude: It is ſo called, becauſe it equally divides the Globe into two Hemiſpheres. Croſs this at any aſſigned Point, is a Semi-circle imagin'd to be the Meaſure of Latitude to all particular Places through which it paſſeth, which is call'd the Meridian; becauſe, when the Sun cometh Vertical to this Semi-circle, it makes Mid-day, or Noon at all thoſe Places. By theſe all the other Furniture of the Globe may be determin'd, anſwerable to any particular Place or Point of the Globe, obſerving that the Lines, which Meaſure the Longitude of all Places having the ſame Latitude, are call'd Parallels of Latitude, becauſe they are drawn Parallel to the Equator, from whence the Latitude is reckoned; and all thoſe Semi-circles terminating in the Poles, which meaſure the Latitude of all Places, having the ſame Longitude, are ſeverally Meridians of the Places, thro' which they paſs; and both theſe Orders of Lines take one Denomination from theſe Places themſelves, and accordingly are uſed in the following Treatiſe.

HENCE therefore it appears, that the Geographical Terms, Longitude and Latitude, are Relative Terms; the firſt ſignifies the Diſtance of a Place from any aſſigned Meridian, the other the Diſtance of the ſame Place from the Equator.

THE two Points to which all theſe Lines bear a reſpect, and by which they are Aſſign'd, are firſt immutably fix'd, becauſe the Earth always turns upon the ſame Points; and ſecondly, they are ſenſibly diſcover'd, that is, by Cœleſtial Obſervations, for the Axis of the Earth, or the Line on which it turns, keeps near the ſame Direction, within leſs than can eaſily be Diſcern'd in the Age of a Man, and therefore the ſame Points of the Heavens always appear to the ſame Perſon Vertical to the Poles of the Earth.

TO determine the other Terms, let us conſider the Relation which the Face of the Earth bears to that of the Heavens, by which it is meaſured; particularly while the Earth turns upon its proper Axis, keeping the ſame Direction nearly, all the heavenly Bodies, which have the ſame Diſtance from the Equator, and lie on the ſame ſide of it with any particular Point of the Earth, will ſucceſſively come Vertical to that Place in the time of one Revolution, *i. e.* Twenty-four Hours; ſo that the Latitude of any Place, when the Heavens are viſible, may be hereby found, becauſe the Parallel of Latitude, in which it lies, anſwers to the obſerved Diſtance of its vertical Point in the Heavens from the Equator, or the next Pole. It follows alſo, that by any other Point of the Heavens, whoſe Declination or Diſtance from the Equator is known, if it be obſerved in the ſame Meridian, and its Diſtance from the Zenith or Vertical Point be taken, the Latitude of the Place of Obſervation may be found, by adding or ſubtracting the Latter from the Former, according as the ſaid Point happens to lie nearer to or further from the Equator. This Method is conſtantly practiſed in the Day-time, by Obſervation of the Sun's Meridian Altitude, whoſe Declination we have given in Tables for the Purpoſe to every Day in the Year. In the Night, by the Meridian Altitude of certain Fixed Stars, whoſe Declinations we have in like Tables; now conſidering, that to an Eye placed upon the Earth, an Hemiſphere of the Heavens is viſible in clear Weather, and conſidering that the Poles of the World are Diametrically oppoſite, and therefore will needs fall one in the viſible, the other in the inviſible Hemiſphere, or both in the Horizon, we ſhall then have Advantage enough for determining the Latitude of any Station whatſoever.

BUT now, to find the Longitude we have not the like Advantage of a fixed Point to meaſure from, becauſe the Earth's diurnal Revolution does ſucceſſively preſent different Parts of the Heaven to the ſame Place of the Earth; and therefore the Appearances of the heavenly Bodies, in the ſpace of one Revolution, will be the ſame in all Places of the Earth, having the ſame Latitude; excepting a ſmall Difference, which the change of Aſpects, Poſture or Place mutually in thoſe of them which are Moveable, *(viz.)* the Planets, does make; but then it is to be Noted, That the ſame Appearance of the fixed Bodies at two Places of the ſame Latitude, but differing in Longitude, will not happen at the ſame Inſtant of Time abſolutely, but to the one ſooner than the other, and the difference of Time betwixt each Inſtant thus diſtinguiſh'd, will bear the ſame Proportion to the Period of one Revolution, as the difference of Longitude betwixt the given Places to an entire Circle. Note alſo, that the Diviſion of Time in all Places, being ſuppoſed alike, and regulated by the Motion of the Heavens, (which are the moſt Regular Movers, and therefore the fitteſt Indices of Time;) in the ſame Method this may be call'd apparent Time, becauſe in all Places meaſur'd and denominate by the Heavenly Appearances : Then in the Reckoning of Apparent Time, there will be a Difference in different Places, anſwerable to their Longitude; and conſequently by the Reckoning of Apparent Time alone in different Places, the different Appearances of the Heavens cannot be eſtimate, becauſe that Reckoning is ſtated and denominated by thoſe Phænomena; but on the other hand, if by the Aſpects of the moveable Bodies, the ſame abſolute Time can be aſcertain'd, at any two Places, where they are viſible, then the Difference of Apparent Time, obſerv'd, or otherwiſe known, at each of the given Places, will give their Difference of Longitude; and therefore the main Subject of this Enquiry, will be a Method to make out the Antecedent.

THIS Method is eaſier to be Practis'd at Land, than at Sea: Firſt, Becauſe proper and convenient Inſtruments are more manageable at Land than by Sea. Secondly, Thoſe that reſide long in any particular Country, have the Advantage of proper Opportunities, more ſerving their Purpoſe, than that of Sea-faring Men. For the Longitude of any particular City or Country, being found once, it will always ſerve; but Travellers at Sea oftener want the Longitude, than they have an Opportunity or Advantage to find it, and therefore, what I have to offer upon this Subject, is deſign'd for their Uſe; for the Longitude and Latitude of particular Countries is already given in Charts, and ſuppos'd by the Traveller himſelf, who therefore, by theſe Helps, in the Method here propos'd, is to find his Way thither.

AN

AN
ESSAY
FOR THE
DISCOVERY
OF THE
LONGITUDE at SEA.

THESE Things being premiſed, I proceed now to the Work propoſed: And firſt in General, the Way of Meaſuring Diſtances may be of uſe ſometimes, within Sight of Land, for ſeveral Nautical Purpoſes, and is its ſelf ſufficient to determine the Difference of Longitude, from one end of the largeſt Continent to the other, if the Places given be within ſight of each other, or within ſight of a Third, or if at ſeveral Stations, within ſight of each other, you can join the two Extreams; the Queſtion is eaſily anſwered by the Rules of Geodeticks and Trigonometry; but becauſe this does not directly ſerve our preſent Purpoſe, I muſt refer theſe Queries to the proper Treatiſes upon ſuch Subjects; for in the Main Ocean, out of ſight of Land, there are no Advantages for practiſing this Method, and therefore Authors have gone, as they are obliged, another way to Work. One Expedient is the Uſe of the Log, faſtened to a Line of a known Length, conveniently divided for the Purpoſe, and heaved into the Sea, by which, and an half Minute Glaſs they make an Eſtimate of the Ships Run in that Time, and proportionably for a greater; but uncertain Currents make this Reckoning uncertain. Another Means try'd without Succeſs, was an Engine, towed after the Ship, which by Reſiſtance of the Water, turning a Movement, with one or more Indices, ſhew'd how much Water was quit; but this for the former Reaſon was inſufficient. Others have in vain attempted to find the Longitude univerſally by the Appulſes and Eclipſes of the Moon: Others by the Eclipſes and Aſpects of Jupiter's Satellites; which laſt are both of ſingular Uſe at Land, but little at Sea: Partly, becauſe of the unſteadineſs of the Sea, which doth not admit the Uſe of Inſtruments large enough for Obſervation; and partly, becauſe the Weather, as alſo the Aſpects themſelves, ſeldom ſerve; not to ſpeak of the ſlowneſs of the Moon's Motion, and redundancy of Light. But the Failure of theſe Experiments, ſhould not diſcourage us from farther Enquiries, Whether there be yet any more promiſing Method left of Meaſuring Diſtances at Sea? I believe, we may conclude in the Affirmative: For ſince Nature hath remarkably Diſtinguiſh'd Times in the ſame Place, and Places at the ſame Time, by a ſurprizing Phænomenon in this very Element, it ſhould ſeem a vexatious Diſappointment, and a Reproach upon Humane Incapacity, if this Advantage will not ſerve us to diſcover either.

IF the Theory of the Tide was carefully examin'd, and a ſufficient Number of Obſervations made, in very diſtant Parts of the World, with all the Acuracy and Diligence, which a Thing of this Importance requires, I am perſuaded that it would compenſate the Trouble of the Undertaking, and therefore will endeavour to Determine this Queſtion, by conſidering Particulars.

IT is commonly known, That though the Time betwixt every Alternate Flood and the next, is equal nearly to the Moon's Diurnal Revolution at the ſame Place, yet at different Places, a few Miles diſtant, the Time of Flood is not the ſame, which ſufficiently ſhews, that though the Tides follow the Moon, yet they do not, and cannot keep Pace with her, *i. e.* cannot quit the ſame Arch of a Circle, in the ſame Time: No, nor the hundredth part of the ſame Arch. Therefore if this Theory can be truly Stated, and the Ebbing and Flowing of the Sea be made ſenſible on Shipboard, out of Sight of Land, the Time of the Day will ſhew the Place, and conſequently determine the Longitude, within ſuch a Compaſs as the Tide runs in twelve Hours Time; ſo that here are two Queſtions to be anſwer'd.

Queſt. I. HOW the Riſing and Falling of the Water may be diſcern'd out at Sea?

Sol. THIS ſeems poſſible to be Determin'd by the portable Barometer, not without ſome Trouble; for as the Water riſes or falls, ſo muſt the Ship; and this Inſtrument is found by Experience proper to take a Level, the Mercury falling as the Inſtrument riſeth, and contrariwiſe; ſo that if it be carry'd to the top of a Mountain, it will ſtand a conſiderable Degree lower, than when at the foot of the Mountain. Particularly, it is found to riſe and fall for every thirty Yards perpendicular one Degree,

gree, or one tenth of an Inch. Now the height of the Tides in theſe Parts of the World is about two Fathom, or four Yards, then for this height the Mercury will fall about a Centeſm of an Inch, which indeed is but a ſmall matter, and not to be diſcern'd eaſily in Barometers of the common Sort; but there have been Barometers made, which would vary for every Inch of the common Sort 20: In theſe therefore the ordinary heighth of the Tides would alter the Mercury about one fifth of an Inch, which is eaſily diſcern'd.

Mr. *Hawksbee*'s Barometer is of this Sort; but for ſeveral Reaſons inſufficient in our Caſe, and therefore we muſt think of another.

THE Make of this Inſtrument, fit for our Purpoſe, will differ not only from the common Ones, but alſo from that laſt mention'd; becauſe it muſt be both Portable, and in a ſort Diagonal; therefore it will be neceſſary to deſcribe it.

THE perpendicular Tube may be of any Form Diameter, or Matter that will endure the Quickſilver; but for Convenience, it is beſt to have it ſtreight, of a ſmall Bore, that leſs Mercury may ſerve; and ſince it is not needful it ſhould be Pellucid, if of Glaſs, it may be enclos'd in Wood or Braſs to ſecure it. The length of it muſt be 28 Inches, more than the perpendicular Range of the Mercury at the Bottom; of which by and by. At the Top it muſt open into a large Cavity, 3 or 4 Inches in Height, and about 2 or 3 in Diameter, clos'd at the Top, having no other Paſſage, but into the Tube. This I ſhall for Diſtinction call the Chamber. At the bottom of the firſt, and communicating with it, muſt be a ſecond ſmall Glaſs Tube,

Tube of as great a length as can well be, wreath'd ſpirally about the former, as its Center, into the Figure of a very obtuſe Cone, with its Point downward, ſo as that each Wreath may gradually, but as little as Art can allow, aſcend above the foregoing, provided the Length will anſwer; but let the outmoſt End of it be wrought off perpendicularly, in an upright Poſture about an Inch or two. The perpendicular Height of this Cone ſhould be two Inches from the Point to the Baſe, and this I call the Range of the Mercury. The extream Orifice ſhould be wrought on the inſide truly Cylindrical, and to it a Stopple fitted very cloſe, to prevent the Mercury's falling out when the Inſtrument is laid aſide. The outſide of the torcular Veſſel muſt lie open to View on one Side, *i. e.* the uppermoſt; but to ſtrengthen it underneath, it may reſt upon a braſs Plate: So alſo the perpendicular Portion of the Tube may be incloſ'd in a ſtrong Caſe to the Top, where let there be a Screw to preſs in and out, as Occaſion requires, the cylindrical Stopple. The Chamber and the wreathed Tube (which from its Figure reſembling a Cone, I may not improperly call the Baſin) muſt be ſo proportion'd, that when the former is fill'd to the height of 3 Inches, the other may be entirely empty; and when this is full, that may be empty. Then let the whole compound Veſſel be firſt inclin'd, and fill'd full of Quick-ſilver; then being rais'd, let as much Mercury paſs as will flow out at the Extremity, and when it ſtops, with a pliant Wire, or other ſuch Thing, thruſt into the extream Orifice, having a piece of Cotton fix'd to the End of it, let as much of the Baſin be empty'd as will hold the Remainder of the Mercury ſtagnant in the Chamber: Or rather thus; when the Veſſel is full, let it be directly inverted, till the Baſin has empty'd itſelf; for in ſuch a Poſture, this declines to the open Orifice, and the reſt aſcend, ſo that no more than the Baſin will empty; but then the Chamber muſt be no more than 3 Inches high, or the Baſin anſwerable.

At the Top of the Inſtrument let there be a Hoop or Ring to hang it upon during the Uſe or Obſervation made by it.

Things being thus diſpos'd, the Effect will be this; The Baſin riſing from the lower end of the perpendicular Tube, to the height of two Inches, beſides the Appendix, it will keep the Mercury ſuſpended, (as well as the Baſin of the ordinary Sort) when it is open'd, and while that in the Chamber ſubſides, to an equilibrium with the Atmoſphere, by its own Weight (as in ordinary Barometers) it muſt needs empty into the Baſin; and contrariwiſe, when the Baſin empties, the Chamber muſt fill. But the Bore of this, by the Suppoſition, is much larger than of that; conſequently, a ſmall Variation in the one will be eaſily ſenſible in the other; for which End, let the outward circumference of the Baſin be graduate, and a Thread or a Wire link'd about the perpendicular Tube, which being ſtretch'd to the edge of the Baſin, will, upon the Degrees there, Note the Variation of the Mercury; for this, when it riſeth or falls, muſt, as the Tube directs, run circularly.

Hence it follows, that when the Inſtrument riſeth with the Tide, the Mercury will do ſo too in the Index; and contrariwiſe. This is the Reverſe of what happens in taking Levels by the ordinary Barometer, which Note is once for all given, to prevent Miſtakes in Application of theſe Principles to what follows.

ANOTHER Advantage of this Inſtrument, is, That by bringing the Index into a narrower Compaſs than that of Mr. *Hawksbee*'s, it is made more tractable in the Time of Obſervation, and eaſily brought into a ſteady Poſture, tho' it hang penduloully, which is next to impoſſible in the other a Shipboard.

THE framing of this Inſtrumeut will be very difficult, and require a great deal of Care, ſo much, that I am aware it will be a great Objection againſt it, and therefore it will be neceſſary to ſay ſomething upon this Article, tho' I am ſatisfy'd by Time and Practice, if it come into Uſe, the Difficulty will almoſt vaniſh, conſidering to what Perfection the working of Glaſs is brought. The Work may be done in Parts, and afterward put together: Or elſe the Baſin may be made of Box or other proper Wood, in one entire Piece, having a torcular Channel cut in the upper-ſide, and cloſe cover'd with Glaſs for Sight: Otherwiſe, if it be moſt convenient, that this conſiſt of one entire Glaſs-Tube, poſſibly it may be wrought in this manner. Having the Tube drawn out at full length, and a braſs Cone poliſh'd and ſhap'd into the deſign'd Form of the Baſin, having a Hole in the Center, let one End of the Tube be put into the Hole, and then the Braſs Inſtrument, together with the Tube, apply'd to a proper Furnace made for the Purpoſe, and of a Degree of Heat not very intenſe; then as the Glaſs begins to yield, let the Inſtrument be turn'd gently and gradually, as the Metal will allow, winding up the Tube from the Center outwards, cloſe to the Braſs Mold; in which Care muſt be uſed that the principal Degree of Heat be apply'd only where the Metal is bending, not without a moderate Heat upon the whole Clue, while the Operation laſts, to prevent the flying of the Glaſs, which yet, if it was too great, would cloſe up the Cavity. As to the Juncture and Inſertion of Parts, I need ſay nothing to a Torrecellian Operator, or any that know how to Seal Hermetically.

In the Uſe of this Inſtrument, the cylindrical Stopple muſt be drawn out, that the Mercury may communicate freely with the open Air; and ſince it is neceſſary to hang it Plumb or Perpendicular, and that pretty ſteady, it ſhould be born pendulouſly by the Hand, humouring the Motion of the Ship, while the Obſervation is made; for this there will be Advantage enough, whatever the Motion of the Ship may be, which if one Inſtant favour, it is enough; ſince the Obſervation may be taken as *in Tranſitu*, which, by the way, ſhould be taken once every Hour in critical and perplex'd Caſes; otherwiſe once in four, except when by conſtancy of Wind and Weather, the Run of the Ship proves nearly equal every Day; for then the Account will require little Attendance.

When it is out of Uſe, let the Stopple be ſcrew'd down, and the Inſtrument laid by carefully, where it may not be liable to any Caſualties, as ſuppoſe in a Caſe made for the Purpoſe, and fill'd with Cotton.

Hitherto I have virtually ſaid nothing, unleſs I anſwer ſome conſiderable Objections that might be made to the Sufficiency of this Expedient: Of which ſeverally.

I. THIS kind of Inſtrument is made an Index of the Weather; and therefore it will be a hard Matter to diſtinguiſh clearly the Variations occaſion'd by this, from thoſe that depend upon the Riſe and Fall of the Water. I anſwer, There will be ſome Difficulty to do this, but nothing like an Impoſſibility: However, before I ſpeak directly to the Queſtion, I muſt Premiſe thus much, That if the Inſtrument will frequently, or for the moſt part, ſerve, it will be ſufficient, and as much as is requir'd. I appeal to the Merchant, Whether he will not be content to miſs the Advantage of Determining the Longitude one Day in a Week, or 1 Day in 3, in Voyages, where it is moſt wanted? And thoſe uſually are the longeſt, eſpecially conſidering, within how ſmall a matter this Expedient will come of Truth, if the Sequel makes good the Premiſes, and that even at Times of the greateſt Uncertainty, it is an eaſy Matter by the Log, to give a near gueſs at the Ship's Run for one Day or two. And farther, I muſt add to this Conſideration, That the finding of the Longitude, is to direct his Courſe, and ſecure his Aim, which the greateſt Error will not perplex, if he can at laſt come to a Certainty; nor is he liable by the failure of the Inſtrument for a Day or two, to commit ſuch an Error, if ſtreſs of Weather doth not drive him into it, which no Means can always prevent. But to the Queſtion: The Return of the Tide muſt happen, when by the Weather the Mercury is either falling, riſing, or at a ſtand. In the two firſt Caſes, it will be no inſuperable Difficulty to diſcern at what Rate it falls and riſes: Of which by and by. This being had; then the Riſe of the Water, when the Mercury is falling, will make a ſenſible abatement in the tenour or velocity of its Deſcent; and the like may be ſaid with reſpect to the Fall; as alſo on the other hand, the Cauſes, when they concur, will, during this Co-incidence, encreaſe the Effect; but when the Weather is ſettled, there is no room for the Objection, *i. e.* in the third Caſe ſuppos'd.

BUT this general and brief Account of the Phænomenon, though it proves that Things are ſo; yet ſhews nothing of the Rules, Laws of Nature, or Meaſures, by which it ſhould be eſtimate, and therefore will give us no Satisfaction, without particular Directions for the Practice of the Problem, in all variety of Caſes poſſible: To which End obſerve,

THAT to determine the Longitude within a League is ſufficient, and all that the Sea-man requires; nay, he will be glad to come within a greater diſtance from Truth, *i. e.* within three Leagues; for ſo far his Sight ſerves him to diſcover almoſt any Thing, worth obſerving, in clear Weather; to effect this, the Time of the Tides Return, within little leſs than half an Hour, is neceſſary to be given by the Inſtrument, as will appear by the Sequel. Now to diſcover this, we muſt not immediately attend ſo much to the preciſe Moment of the Mercury's Return, as to the Times of its coming to any aſſign'd Station, about the middle of its Range, both in its Riſe and Fall; by comparing which we may determine the other within a few Minutes, every Thing elſe being equal. With this Premonition, I ſhall proceed to propoſe all the particular Caſes, which I know of, with the Solutions of the Problem under each of them ſeverally.

1. SUPPOSE the Weather be ſettled for the Space of twenty-four Hours, and the Mercury

thereby no wiſe affected: Having obſerv'd by frequent Inſpection, that the loweſt ebb of the Mercury is to ſuch a Degree; at an Obſervation about ſix Hours after, that it ſtands four Degrees higher; that at the next Obſervation twelve Hours after, it is advanc'd 4 Deg. more; at the next Trial, 18 Hours after the firſt, that it hath fallen 4 Degrees; thence I gather, That the Tide's Return was at the Time of the third Obſervation preciſely, or that then they had High Water, provided the Ship has kept an uniform Motion before, and ſince the Time of the third Obſervation, which is not very difficult to be determin'd. This Caſe happens, when ſhe runs almoſt croſs the Courſe of the Tides, yet a little Veering towards the ſame Point: But if at the fourth Obſervation, I find, that the Mercury has deſcended but 3 Deg. *i. e.* ſtands a Degree higher, than at the ſecond Obſervation, then there are two Ways of Determining the Queſtion, *viz.* Either 1. by watching the time of the Mercury's attaining the Station aſſign'd, *i. e.* the Station at the ſecond Obſervation, which imagine to be an Hour later; ſo that betwixt the two Times, of its coming to the ſame Station, there be 13 Hours; then divide the 13 Hours into two equal Parts, and each give the Diſtance of the Tide's Return from both the ſecond and fourth Obſervation, *i. e.* after the former, and before the latter, upon the foregoing Suppoſition of the Ship's uniform Courſe. Or 2. by a fifth Obſervation at any Time before the Tide's ſecond Return, which by the following Rules, will ſhew, at what Rate the Mercury falls; then accordingly, making an allowance of Time for the diſtance of the Mercury, at this laſt Obſervation, from the Station aſſign'd, this will ſhew at what Inſtant it reach'd the Mark obſerv'd; from which Time the Tide's Return is reckon'd, as before.

2. Suppose the Mercury hath been vary'd by the Weather, during all the Time of the foregoing Obſervations: This admits of two Varieties.

(1.) That the Weather and the Tides concur in Raiſing or Depreſſing the Mercury: In this Caſe, theſe two Cauſes muſt act either equally, or unequally: I mean, that the Effects of each upon the Mercury, are either equal or unequal; if equal, then they muſt return at the ſame Time, which will be occaſion of no Scruple or Perplexity at all; or elſe there will be a ſenſible ſtand at the Time of the Tide's returning, which will ſerve well enough for an Index, becauſe the Tide or Surge of Water, we are ſpeaking of, is circular, and the Riſe and Fall of it at the ſame Place in equal Times, is in a proportion of the verſed Sines of the ſeveral Arches of the Circle it forms, determin'd by the Diſtance or Line, which the Tide Flows in thoſe Times; therefore if their Effects be equal till the Time of their Turn, both muſt be at a ſtand near that Time, becauſe one we ſee is ſo: But if unequal, then the Inequality of the one does either preciſely compenſate that of the other, or not; if the firſt happens, then either they both return together, as before; which is as well as we could wiſh, to make a Judgment upon the Tide; or elſe the one continues, when the other hath return'd; then it is either in ſuch a manner, as to prolong the Riſe and Fall of the Mercury at the ſame Rate, or not: If the firſt, then it is evident, this muſt be caus'd by the Weather; and therefore ſince the Riſe or Fall will generally vaſtly exceed the uſual Range of the Mercury for the Tides alone; conſequently, when this Variation comes to return, it is impoſſible it ſhould fall in with the other, without either a ſtand, or an abatement at High or Low-Water; and if it does not continue its Progreſs equally, then the Inequality is the Indication we want. The ſame may be ſaid, if the Inequalities of the one do not compenſate thoſe of the other.

(2.) FROM what hath been ſaid already, it appears, what Judgment may be made by the Inſtrument, when theſe two Cauſes happen to counteract, or oppoſe each other; for then the whole Agency of the one compenſates that of the other, or not: If the firſt be ſuppos'd, then the Mercury continues fix'd at one Station invariably: This, I confeſs is a great Objection, but as it is the moſt unlikely Chance, that can happen, and ten to one againſt it, is no raſh Venture; ſo neither is it altogether without a Solution; for tho' I do not inſiſt upon it, that ſuch a Thing muſt be occaſion'd by a ſmall, but very ſudden Change of the Weather, of which our Senſes might make a Judgment, pretty near Truth, as to the Effect it muſt have upon the Inſtrument; yet the Thermometer, I am perſuaded, will in ſuch a Caſe ſympathize with the Barometer, and ſerve to ſhew when the Return happen'd. But if they do not compenſate each other, then the Return of the Mercury, depending upon each, will be diſtinct. Now in this Caſe there is one Objection, which is all that need to be farther conſider'd in this Article, that is, the Return made by the Weather and that by the Tides, may happen ſo near one another, that they will hardly be diſtinguiſh'd; or if they be, yet which ought to be aſſign'd to this Cauſe, and which to the other, will be difficult to Determine. As to the firſt, When they happen ſo near each other, as not to be diſtinguiſh'd, it will be of leſs Conſequence, ſince the Space of almoſt half an Hour is allow'd for the exacteſt Determination of the Queſtion deſir'd. As to the ſecond, The Time from the laſt Return of the Tide, together with the Run of the Ship in that Time cannot unqueſtionably, except in ſome extraordinary ſtreſs of Weather, fail of Deciding this Matter.

THE Range of the Mercury for the Weather, will be very large; which therefore will yield a great Advantage, to judge at what Rate it riſes and falls in moſt Caſes To this, there is only one material Objection, that I know of, to be made, *viz.* That the Riſe and Fall of the Mercury for the Weather, may happen to be very irregular, *i. e* by fits and ſtarts. This is impoſſible to be determin'd, but by Obſervation and Experiment; but yet if we conſider the Nature of the Cauſe, on which it depends, the contrary ſeems probable; for I cannot conceive, how ſo fluid a Body as that of the Atmoſphere, can, from any Natural Cauſes, receive any Alteration, but gradually, and therefore regularly, conſidering that the free Communication, which its Fluidity affords to one Part with another, will prevent any other Indication by this Inſtrument, beſides that of the general Temperature of the Air in and about thoſe Places, of which, whatever ſudden Alterations may happen, yet their Effects, from the Beginning to the End (that is, from one Return of the Mercury to the other) will be, upon the mention'd Suppoſition, firſt leſs, and then more, in ſuch a certain Proportion, as the Fluidity of the Air, being conſtantly and invariably the ſame, doth admit; therefore Regular, unleſs more Cauſes than one, at uncertain Times, do concur or oppoſe each other, which I queſtion not, that the Thermometer will take ſome Notice of; to which I muſt add, what I have already Hinted in other Caſes, That this will be a rare Singularity. Now, if upon theſe Conſiderations, the Suppoſition be granted me, then this Account will be eaſier; which becauſe it will be anſwerable to that of the Tide, I ſhall Conſider them both together.

HERE let us enquire, into what Figure the Flood forms itſelf; which is to be determin'd, by conſidering it in ſeveral Poſitions; for regarding the Extent of it, as projected upon the Plain of the Horizon, it is either Circular, Elliptical, or Parobolick, (according to the Poſition of its Cauſes and Circumſtances, mention'd below) but doth not belong to this Place. A ſmall Portion of it, is the Segment of a Cylinder. The Line which the Surface of the Tides would make, by interſecting a Plain Perpendicular to the Horizon, and in the ſame Direction with their Courſe, I judge, will be a Curve compos'd of certain circular Arches, larger, or leſs, (according as their Diſtance is leſs or more, in proportion to their height) whoſe Poſition is Alternately the reverſe of each other; that is, the one bending up, and the other down: For I ſee no Reaſon from their Cauſes, why they ſhould not conform to the ſame Figure, that other waving Liquids do. Now we find, that naturally they compoſe themſelves, as much as external Cauſes and Circumſtances allow, into a globular Form: But this I muſt leave to Obſervation. Now upon this Hypotheſis, at what Rate the Tide riſes and falls at the ſame Place, may be judg'd by the proportion of the Verſed Sines of theſe Arches; and the Variation occaſion'd by the Weather, is likely to prove anſwerable.

(2.) THE Riſe and Fall of the Veſſel in a rolling Sea, will conſiderably vary the Mercury, but not ſo as to hinder or perplex the Obſervations; for as the Time of High-water, may be diſcern'd in a Storm, as well as in a Calm, upon the Shore, or where may be taken any Gauge of its Height, not-notwithſtanding its Undulation; ſo the waving of the Quick-ſilver, anſwerably thereto, may be eaſily determin'd within a certain Limit by the Index, of which the true Station in a Calm will be near a Medium.

IN ſhort, with Regard to all that has been yet ſaid of this Inſtrument, I add, It will be ſerviceable to more Purpoſes than thoſe, to which it is here apply'd: Nor do I recommend it as a general Expedient, but allow, that in ſome few particular Places and Times, it will be uſeleſs.

TO diſtinguiſh theſe Variations mention'd, the following Notes, I hope, will be ſufficient. Firſt, that which is occaſion'd by the unſteadineſs of the Hand that bears the Inſtrument in the Time of Obſervation, will be quick, ſmall, ſenſible and irregular. Secondly, That which depends upon the Undulation of a rough Sea, will be ſlow, ſenſible and regular. Thirdly, That which ariſeth from the Weather, will, for the moſt part, be inſenſibly ſlow and irregular. Fourthly, That which is cauſ'd by the Tides, will be inſenſibly ſlow, regular, and generally a Medium betwixt the two laſt mention'd.

Queſt. II. BY what Rule ſhall the Time of High-water be found in any given Place, or the Place be found by the Time of High-water given?

Sol. THE full Anſwer to this can be given only by Experiment, as was above Hinted, and a Table made, partly by actual Obſervation, for the moſt frequented Places ſufficiently diſtant, and for the reſt by a general Analogy, ſo far as it may be demonſtrated from thoſe Experiments. However, in this Place enough may be ſaid both to ſatisfy a Queriſt, and direct in the Obſervation. As particularly,

1. THE Accounts which we have of the Tides, ſhew them to be variable, in ſo much, that they have been reckon'd altogether uncertain, not in all Places obſerving the ſame Order, Courſe, Time, or Depth. This doth proceed partly from the various and promiſcuous Poſitions of the Sea and Land mutually, and by conſidering Particulars, as many, or it may be more Varieties may be accounted for, than by Report we have yet receiv'd; partly from the Inequalities of the Cauſes, as well as the Recipient Subjects. So that theſe Appearances are no Reaſon to deſpair of Adjuſting and Reducing them to a Calculation, if their Cauſes can be aſſign'd.

2. IT is undeniably apparent, and univerſally granted, That the Moon is the chief Cauſe of the Tides: For, according to the receiv'd Laws of Nature, all Bodies do mutually attract within the Sphere of their Influence, in a certain Proportion to their Diſtances, and conſequently the Moon, which is by much the neareſt of all the Heavenly Bodies, muſt have the greateſt Power upon Sublunary Bodies, of which only Fluids do Immediately diſcover a ſenſible Effect. For Mediately (*i. e.* by the viciſſitude of the Tides) we may diſcover, that even the whole Body of the Earth is

ſomewhat affected by the Moon's Attraction. The Effect which this Cauſe has upon the Ocean, is an altering of its Equilibrium in the Place affected, where it has free Communication with other Parts of the ſame Fluid, which are either not at all, or leſs affected; for it cannot raiſe the Water abſolutely, or ſuſpend it in the Air, becauſe of the Earth's nearer and greater Influence; and therefore in a ſmall Lake, or Inland-Sea, ſuch as the Sea of *Galilee*, or the *Caſpian*, there can be no Riſe, for want of a Supply from other Parts, where the Moon's Influence is leſs; all the Parts of theſe Seas being equally affected at the ſame Time.

(3.) THE Tide is an Eddy or Surge of Water; and therefore continually tends to an Equilibrium, as ſoon as the external Impulſe, which caus'd it, doth ceaſe or remove. Now ſince the Water after a Flood, can recover the Equilibrium only by flowing to, and ſupplying the Places where the Vacancy was before, it muſt needs ſpread and propagate itſelf every way quite round, where it finds a free Communication; and conſequently, muſt decreaſe and ſpend itſelf and force, as it ſpreads into a larger Compaſs proportionally, or elſe retain its Height and Celerity, as it happens to be contracted.

FROM theſe Premiſes it follows, That the firſt and general Tendency of the Tides, muſt be according to the Courſe of the Moon, on which they depend, from *Eaſt* to *Weſt*; but ſecondarily, according to the Situation and Form of the Sea, it may be alſo from *North* to *South*, and from *South* to *North*; nay, ſometimes the Tide may happen to ſet from *Weſt* to *Eaſt*, in Straits which have no Communication with the Ocean, but from the *Weſt*. Particularly in the *Atlantick*, *Indian* and *Pacifick*

Oceans, which are of a vaſt Extent, the Tides unqueſtionably keep their Natural Courſe, and will riſe in ſome Places to a conſiderable height; but in the Northern Ocean, their main Courſe will be Northward; and ſomething of the contrary will happen in Seas of a conſiderable *South* Latitude, but not ſo much, by reaſon of the vaſt Southern Continent. Now as for the *Mediterranean*, which has no Communication with the Ocean, but thro' the Straits of *Gibraltar*, there may be ſome Tides, becauſe its Reach from *Eaſt* to *Weſt* is conſiderable; but thoſe Tides can be but ſmall, not much above a tenth part of what happens elſewhere. In the *Baltick* and the *Red-Sea*, there will ſcarce be any ſenſible; they will not be great in *Hudſon's-Bay*; in *St. George's*-Channel and the *German*-Sea, they will ſet contrary Ways, and when they meet near the Mouth of any River, will raiſe in it a very eager, ſudden, and impetuous Tide. In the Britiſh Channel the Tide muſt run from *Weſt* to *Eaſt*: In all Rivers they will run from the Sea inwards.

HENCE alſo we may obſerve, That from the Weſtern Coaſt of a large Continent, the Tides will take their firſt Riſe in the ſucceeding Ocean, if it be large enough, and lie in the Torrid Zone, and this when the Moon comes vertical to the Meridian, where they ſtart, or to the oppoſite Meridian; thence extending themſelves Weſtward, they follow the Moon, but cannot proceed as faſt as ſhe; therefore at the firſt Riſe they will be but ſmall, till the Moon overtaking them in their Progreſs, raiſeth them a little higher, than they could riſe at the firſt Lift, by reaſon of her ſpeedy Departure. The like Effect will the third, fourth, and following Revolutions of the Moon have upon the ſame Flood; conſequently, they will in their Progreſs continually increaſe, till they either receive the utmoſt Effect which this Cauſe can produce, or break themſelves upon an oppoſite Shore; therefore it may well be expected, that upon the Weſtern Coaſt of *Congo* and *Peru*, very ſmall or no Tide will be diſcern'd, eſpecially the latter, for a Reaſon to be mention'd below. This Effect of the Moon, is very much like that of the Wind, when it blows upon a ſtagnant Water, raiſing Waves proportionable to the Depth and Extent of it, which begin on that ſide, whence the Wind drives them, and are there very ſmall, but as they proceed, do gradually and orderly increaſe, till they reach the oppoſite Shore; therefore, by a parity of Reaſon, we may conclude, that there are higher Tides on the Eaſtern Coaſt of large Extent, than the Weſtern, every thing elſe being equal.

BUT yet it is to be Conſider'd, That the circular Progreſs of the Flood will ſomewhat vary theſe Obſervations, as alſo the freer Communication betwixt one Ocean and another, as particularly betwixt the *Indian* and the *Atlantick*; for which Reaſon the Tides on the *South-Weſt* Coaſts of *Africa*, will be greater than on the *Weſt* of *Magellan*, the Paſſage being larger by the Cape of *Good-Hope*, than the Straits of *Magellan*; the like Argument will hold for an higher Water at Cape *Verd*, than on the *South-eaſt* Coaſt of *Guinea*, the latter lying much *Eaſt* of the former.

NOTE farther, That the various Poſitions and Progreſs of the Moon in her monthly Motion, will ſenſibly augment or diminiſh the Tide in the ſame Place, accordingly as her Declination and mean Motion together doth concur with, or croſs the Course of the Water: As for Inſtance; Such is the peculiar Situation and Figure of the oppoſite Shores of *Africa* and *America*, that the intermediate Ocean lies from *South-Eaſt* to *North-Weſt*, and therefore the Tides, which are rais'd while the Moon paſſeth from the Tropick of *Capricorn* to that of *Cancer*, will be greater at *New-England*, *Virginia*, and the *Lee-ward Iſlands*, whenever they arrive, (for which ſome Time muſt be allow'd) than thoſe, that attend her in her return.

THE laſt Remark of this kind I ſhall make, is, That thoſe Tides which are rais'd in any conſiderable Latitude, yet near the *Zodiack*, muſt be ſomewhat greater than in the *Equinoctial*, *Cæteris Paribus*; becauſe the Moon in her Diurnal Courſe, deſcribes a leſſer Circle, when ſhe declines either *North* or *South*, than when ſhe is in the Equator; and therefore the Tides, ſeeing they conform to the Moon, which riſe near the Tropick, will be longer within the reach of the Moon's Influence, than thoſe which begin in or near the Line. Beſides, thoſe Tides, which ſet towards the Poles, muſt mutually encroach upon and augment each other, as the Meridians, by which they ſteer, approach nearer to each other from the Torrid to the Frigid Zones. But yet ſome Abatement muſt be made in this Article, for their receding from their Original, and ſpending themſelves in their progreſs.

ALL theſe Conſiderations put together and well weigh'd, will, I hope, ſufficiently demonſtrate, that the Variety of theſe Effects doth not render them uncertain or uncapable of a Calculation, and that it is very Unreaſonable to reject or deſpair of a Rule, becauſe the Regularity of them is not obvious to every Obſerver at the firſt View. Now if theſe few Remarks be confirm'd by exact and credible Experiments, at the Places mention'd, the reſt of our Work will be eaſy enough, *i. e.* to Calculate a certain and univerſal Table for finding Diſtances at Sea by the Ebbing and Flowing of it: To conſtruct ſuch a Table two Things will be requiſite; 1. To determine the Periods. 2. The Courſe of the Tides.

To determine the Periods of the Tides, that is, how far they move in any certain Time, we have one Advantage in the Common Table of the Tide, for the moſt frequented Ports in and about *Britain*, by examining which, and comparing each Article carefully, we ſhall find, that the Tide commonly flows in this Latitude about twenty Leagues in nine Hours, and a little more, that is, about twenty-ſix Leagues in twelve Hours; therefore two Places at that Diſtance, and bearing upon the Direct Courſe of the Tides, will have High-water at the ſame Hour of Day and Night. So much therefore I ſhall for Diſtinction call one Stage, in theſe Parts of the World, and Places anſwering; but then regard ſhould be had to the different Depths of the Tide: for at its firſt ſetting-out, this will be but ſmall, and its Motion anſwerable; as by this eaſy Experiment may be made appear; If a Stone or Fiſhing-pole be violently plung'd into a ſmooth, ſtill Water, the Wave thereby rais'd, will be much larger and ſwifter at the Riſe, than after it hath much expanded itſelf. Therefore one Thing to be enquir'd into by Experiments, is, the Time and Depth of the Flood in other Places? A few Obſervations made on the Weſtern Coaſts of *Africa* and *America*, will State this Account right by the Rules of Proportion.

THE Courſe of the Water is to be determin'd on the Artificial Globe, by Lines drawn directly from the ſeveral Points, where the Moon ſucceſſively comes vertical, in both her Diurnal and Menſtrual Courſe, every way, obſerving, where and how theſe ſeveral Rhumbs from different Centers do interſect or lie Parallel. This will determine their Courſe in the large Oceans, where they have no Impediment; but in Creeks, Bays and Straits, for every Turn a new Center is to be aſſum'd, obſerving, that where their Inlets gradually contract, as they proceed, their Force and Depth is ſomewhat augmented; and where they gradually open or expand, they decreaſe, but not proportionably, and therefore the Tide, which is propagated thro' a narrow Strait into a wide Sea, muſt be allow'd to be very ſmall, unleſs accidentally reinforc'd by another Tide from another Quarter; as it happens in the *Germain*-Ocean, where there is one from the Straits of *Dover*, another coming *North* about from *Scotland.* And here by the Bye, obſerve, that their Retreat after a Ren-counter, will raiſe a ſecond Flood or Half-tide, the Reverſe of the firſt.

NOW by ſuch Rules as theſe, founded upon, and confirm'd by Experiment, an Univerſal Tide-Table may be fram'd, not only for the Sea-Coaſts, but alſo for any part of the main Body of the Ocean, which, without doubt, would Meaſure Diſtances, if by the Inſtrument propos'd, the Riſing of the Water can be made ſenſible a Ship-board. In the Uſe of which it is to be noted, that immediately the Table is deſign'd to ſhew how much of every Stage is Run, *i. e.* how much of twenty-ſix Leagues, in which Diſtance the Tides fall at the ſame Hour of the Day or Night. Thus, when by the Inſtrument I find I have High-water, I conſult firſt the Heavens for the Time of the Day at the Place of Obſervation, or elſe the Watch ſet by the Break and Cloſe of Day, according to the Latitude otherwiſe found; then I conſult the Table in the given Latitude, Age of the Moon, and Hour of the Day, which will ſhew me in how many Places at once the Tide falls at that Hour, and Latitude. Then I conſult the Table again for the Hour of the Day at the Place of Departure; obſerving alſo, whether the Courſe of the Ship, and that of the Tide concur, or are contrary, and making an Allowance accordingly, the difference of Times, by the foregoing Proportion, will give the number of Leagues Run in that particular Stage where I then am, reckoning the firſt to begin at the Place of Departure, and every Stage to contain the Run of the Tide in twelve Hours. But then by this Method is not immediately diſcern'd, how many Stages are paſs'd, but mediately it will be helpful, by keeping carefully an Account of the Stages ſeverally, as they are paſs'd: And thus the whole Diſtance of the preſent Station from the Place of Departure may be found. However, if by Omiſſion, (not unreaſonably too long) or any other Accident, the Account be interrupted, the dead Reckoning being to that Time corrected hereby, will ſupply it for a ſmall Space; nay, the Moon herſelf will come very near reducing it to the Compaſs of one Stage. Thus by Meaſuring Diſtances, the Longitude may be Determin'd at Sea.

WHAT I have here ſaid, is principally deſign'd for their Satisfaction, who will have Patience to try Experiments, and improve all Advantages poſſible for making this very Uſeful Diſcovery, till the propos'd Methods by Practice be made eaſy, and fitter for ſuch Hands as will not take any Pains or Trouble; to ſuch the fore-going Propoſal is not Recommended.

II. HAVING examin'd the Nautical Way of Meaſuring Diſtances Immediately, which to me ſeems moſt likely to anſwer Expectation; in the next Place I ſhall enquire, how to find the Longitude at Sea by Difference of apparent Time, at the Place of Departure and the Place of Obſervation, which difference of Time, if it can be determin'd, will (by the Confeſſion of all, that have writ upon the Subject,) ſolve the grand Problem; this hath been attempted ſeveral Ways, which are all reducible to theſe two Expedients, The equal Meaſure of Time, ſhewing the Hour at the Place of Departure, and the Obſervation of the Cœleſtial Motions, which will give the Hour at the Station to be determin'd.

TO Meaſure Time equally a Ship-board, ſeveral Means have been try'd without Succeſs. Some have been ſo Raſh, as to depend upon a Pendulum Clock; but there is no Ground to expect any Certainty, or indeed Effect in ſuch an Inſtrument at Sea, which even at Land requires a ſteady firm Poſition, that ſhaking of Walls or Wind may not affect. The fitteſt Meaſure of Time now in Uſe for our Purpoſe, is the Motion of a Pendulum Watch; but even this hath been found to be very uncertain at Sea; and this may well be expected, for even at Land it can never be made to go at a Certainty, though it be carefully laid in a ſteady Poſture, where Nothing but the Weather can come at it, if it be of the ordinary Make. This I have frequently and diligently try'd, but never with Succeſs; it will therefore be much more difficult at Sea, where, in ſome Parts of the World, the Dews are ſo great, as to Ruſt or Canker almoſt any Sort of Metal, tho' laid up ever ſo cloſe. But neither ſhould this wholly diſcourage us in the Search, till we have try'd all Expedients, both in Theory and Practice. Therefore accordingly, I ſhall here enquire First, How a Movement or Piece of Watchwork may be Regulated or Adjuſted? And if not, Secondly, How it may be Corrected?

To Regulate a Watch, the Invention now commonly uſed, is the Pendulum-Spring, or a Spring faſten'd to the Balance, and imitating the Swing of a Pendulum; which though it reduces the Motion very near to an Equality, ſo that ſometimes the Watch will preſerve, for a good while together, an equal Motion, yet it is found not to ſerve long; which if we examine particularly, we ſhall eaſily be ſatisfy'd of the Reaſon of it. As for Inſtance, That the Weather hath a mighty Influence upon Springs, appears, in that it will ſometimes ſnap the Main-Spring quite aſunder, as I have experienc'd myſelf, and this, when it was not upon the utmoſt ſtretch; then whatever Sort of Weather puts the Spring to ſuch a ſtreſs, muſt needs make it vibrate quicker, and conſequently carry the Index faſter; which Effect muſt be as uncertain as its Cauſe; and therefore we muſt think of ſome other Means to rectify the Watch, which is the more likely, becauſe the Pendulum-Clock is already brought to ſuch an Exactneſs, that if it was poſſible to preſerve the ſame Regularity at Sea, as at Land, would determine the Longitude within a League. Therefore let this Enquiry be directed by the Compariſon of theſe two Movements, that we may ſee whether it is poſſible to make a Pocket Watch as truly and regularly Pendulous as the Clock; which I believe might be done, by applying the Influence of a Loadſtone to the Balance, and ſuiting the Materials and Structure hereto, thus; Let the Balance be made of Braſs (though the Verge and Paddles muſt of neceſſity be of Iron or Steel) of ſuch a Weight and Size, as the main Spring will conveniently allow; but the bigger and heavier the better; Let the Weight of it be carefully balanc'd on all ſides from the Center, with all the Nicety and Certainty poſſible. Croſs the Balance diametrically, a ſmall Channel ſhould be cut, to receive an oblong Piece of Steel, of a Size that will ſuit with the weight and bigneſs of the Balance; this for Diſtinction, I ſhall call the Bar. Then let this Steel Bar be ſtrongly excited with a Loadſtone at both Ends, with contrary Poles, and then carefully put in, that it do not alter the Equilibrium of the Balance; the Pevet of the Verge muſt come thro' the Bar, by an Hole made in it for the Purpoſe, and that very ſmall, without any allowance in the breadth of the Bar at the Center, for fear of diverting or interrupting (in the leaſt) the Magnetick Influence; then the Bar being put in very carefully, that it be not ſway'd or pain'd in its Motion, as alſo the free Swing of the Bar at both Ends being mark'd, let a Loadſtone be fix'd over the Bar, ſo as that each End of the Bar may be next the Pole, that attracts it, and each Pole of the Loadſtone preciſely over the middle Point of the Swing, ſo as that the Bar may freely vibrate without touching at either End, and as much on one ſide the attracting Point as the other. Things being thus fix'd, it is obvious that the Weight of the Balance requir'd to make the Motion ſteady and conſtant, will not only ſwing the Bar much farther, than the Beat of the Crown-wheel requires, but make it very obnoxious to Accidents; ſo that even a ſudden turn of the whole Machine might throw the Bar out of the Influence of the Loadſtone, if the Balance be large, and the Stone but weak. Beſide, upon the very Hypotheſis aſſum'd (in imitation of a Pendulum) the larger Swing is leſs convenient, and therefore it will be for theſe and ſuch like Reaſons, neceſſary to have a Pendulum-Spring to the Balance, which I think cannot be in this Caſe an hindrance of the Deſign, if it do not command the Swing.

THINGS being thus put together, I think I may aſſert, that ſuch a Movement is truly Pendulous, and that it will have all the Properties of a Pendulum-Clock, ſo far as it anſwers in the Structure. I will not undertake to enſure upon this Contrivance, becauſe the beſt Contrivances of this Sort, may be liable to many unknown Accidents in the Uſe of them, or at leaſt, ſuch as cannot be foreſeen by the Authors; yet this I muſt ſay, that by Experiments like this, but very imperfect, I have reduc'd the Inequalities of a very irregular Piece, to an inconſiderable Matter; and withal, I think I may ſay, that no perfect Experiments are to be expected, till the Workmen, on whom they depend, are made Maſters of the Theory; for alas, all the Direction and Caution that can be given them, while they are themſelves leſs intereſs'd in the Thing, will hardly make them careful enough, but when once it is made plain to them by the Reaſon of it, they will better know how to humour it in the Workmanſhip, and ſuit the Temper, Form, and Size of Materials to the Deſign. Again I repeat, what I hinted before, That Experiments of this Nature, and Deſigns of this Importance, ſhould be made in concert, and not depend upon one Head or one Purſe; eſpecially ſince Projectors above moſt People, are obnoxious to Abuſes. What I ſpeak of the firſt Eſſay, which muſt determine the Queſtion, ſhould not be the Rule to judge of the Inſtruments, when they come into common Uſe; and that Uſe has made the Workmen readier; therefore the Deſign is not the worſe, for its requiring ſo much Care and Time at firſt.

I KNOW that the Load-ſtone hath been try'd to regulate a Pocket-Watch; but whether or no in this Way, we cannot tell: By the Account I have had of it, no ſuch thing appears; and I believe no ſuch Experiment ever was made with that Care and Exactneſs, which it requires, to draw a certain Concluſion from it.

IT is obvious, that the Balance, like the Pendulum of a Clock, will have a ſtrong Tendency to one Poſture, and that is, where the Bar conforms to the Load-ſtone, but the force of the main Spring will keep it from reſting there, ſo that it muſt vibrate after the ſame manner as the Natural Pendulum; and yet it is obvious, that the Weight of the Balance will abſolutely command the Swing in Proportion to the ſtrength of the Load-ſtone, both which being almoſt invariably the ſame, it will not be liable to any conſiderable Variations, excepting what ariſeth from the Decreaſe of the Stone's Influence, by its lying in an inconvenient Poſture, or ſuch like Cauſes; to prevent which, the whole Machine may be ſlung, or plac'd vertically, like the Needle, that the Stone may retain or recover its Natural Poſture, which is the more adviſable, becauſe this will ſecure it from other Accidents.

THE beſt Demonſtration of the Premiſes is Experiment, and therefore I ſhall ſay nothing farther on this Head, but that I cannot ſee any material Difference betwixt this Way of hanging the Balance, and the common Poſition of the Pendulum.

It will not be amiſs here, to mention another Way of Correcting a Pendulum-Watch, which, though it be not infallible, will appear by the following very promiſing, nor altogether to be ſlighted; that is, a careful and exact Obſervation of all the Variations of the Watch, anſwerable to all the poſſible Cauſes, from which thoſe Variations may proceed. To determine which, I believe we have ſufficient Advantages; for if we conſider, what theſe Cauſes are, and what Effects all or moſt of them have upon this and other Subjects; we ſhall have no Reaſon to queſtion, that their Influence upon the Movement may be adjuſted and reduc'd to a Calculation, by ſuch Experiments, and that Calculation render'd ſerviceable and applicable to any Movement, by the Diſcovery which other Effects upon like recipient Subjects, do make of the Action and Efficacy of the Cauſes, whatſoever they be.

To this End, I have for ſeveral Years employ'd myſelf with all the Care and Diligence I could uſe in adjuſting a very good Pendulum-Clock, and obſerving thereby all the Variations to which it is incident; not becauſe I queſtion'd the Truth of Mr. *Flamſtead*'s Tables of Equation of Time, (of which all my Obſervations are a manifeſt Proof,) but becauſe I had Reaſon to ſuſpect, that the Clock itſelf would neceſſarily vary from equal Time, as well as the Sun; whereas the Tables mention'd, give us only the variation of the Sun from equal Time. Now conſidering, how near this Incomparable Invention of the large Pendulum-Clock comes to Truth, I promis'd myſelf, that it would not be very difficult to determine its Variations, whatever Cauſe they did depend upon; therefore that the Cauſes themſelves would quickly emerge, and accordingly it has ſucceeded. Now ſince there muſt be a conſiderable Agreement betwixt a Pendulum-Clock and a Pendulum-Watch, I ſhall here give a diſtinct Account of this Undertaking for theſe Reaſons.

Firſt of all, BECAUSE by the Rules of Proportion, the Weight and Semi-diameter of the Balance being nicely Determin'd, and compar'd with the Weight and Length of the Clock's Pendulum, all the Variations of the Watch, proceeding from the ſame Cauſes, are likely to be adjuſted.

Secondly, THESE Experiments made by the Clock, are a Proof, that the Cauſes to which Movements of any Sort are obnoxious, may be found by a careful Fore-caſt, and attentive Obſervation.

Thirdly, BECAUSE theſe Obſervations themſelves, are the plaineſt and readieſt Index of Equal Time, by which the Watch muſt be adjuſted; nay, there is no other, except that of the Heavenly Bodies, which doth not always ſerve, by reaſon of cloudy Weather and uncertain Refractions.

Fourthly, BECAUSE the Method herein follow'd, will direct by what Means we may come to a Certainty in the Variations of the leſſer Movements, with theſe Premonitions,

1. THE Watch is liable to more Variations than the Clock, becauſe it is obnoxious to the Influence of more Cauſes; as particularly, a circular Motion of the whole Machine; but this may be prevented by ſlinging the Caſe, as above deſcrib'd, as alſo the undulous progreſſive Motion of the whole Frame; but this will be but ſmall, eaſily accounted for, and adjuſted by Experiment.

2. THE Strength and Length of the Pendulum-

Spring, will make it diſproportionably receptive of their Influence; but this alſo may be aſcertain'd by Experiment, provided, that every ſingle Piece be diſtinctly try'd, before it be uſed; and the Uſe of the Thing is a more exact Proof of the Effect, than the moſt careful and exact Meaſuring or Adjuſting the Materials themſelves.

NOW by Obſervation I found, that the Pendulum-Clock, of the common Make, which ſwings Seconds, had two different Variations from equal Time, depending upon two different Cauſes; the firſt was the different Temper of the Oyl, which when it was freſh, and the Clock newly clean'd, made it go faſter; but when it grew old, or had lain long, (which in the Courſe of the Experiments was uſually about two Years) it ſenſibly retarded the Motion, which was quite contrary to my Expectation, as I ſhall Note preſently. The ſecond was the different Temper of the Air; which is two-fold, *viz.* a Difference in the Degrees, (1.) Of Heat and Cold. (2.) Wet and Drought: Theſe two Variations in the Weather, I confeſs, I could not by any Expedient diſtinguiſh nicely in the Motion of the Clock; but this I found, that for this Reaſon it was not needful to be Determin'd, and I found however a Way to balk it; ſo that we need to regard no other Affections of the Weather, than thoſe of Heat and Cold; becauſe the Oyl, upon which the Motion depends, is only, or mainly receptive of theſe; ſo that in hot Weather it goes ſlower, and in cold Weather faſter; becauſe that Cold coagulates the Oyl, and makes it leſs apt for the Motion of thoſe Parts it is apply'd to, of which the ſwifteſt Movers ſhow the greateſt Effect: Now the ſwifteſt Movers of a Pendulum-Clock, that receive any Oyl, is the Balance-Wheel and the Paddles that ſwing the Pendulum, which when the Oyl is coagulate,

gulate, act not ſo ſtrongly, and therefore the Pendulum ſweeps a leſſer Arch; but it is the Weight of the Pendulum, which principally ſwings it, and the Length, that adjuſts the Times of its return, whereas the Movement only helps it to perſevere, by ſupplying the Balance to every ſwing of the force, which otherwiſe it would loſe at each Return. Now if it mov'd *in vacuo*, the length of the Pendulum would abſolutely regulate the Swings, which in any Arch, whether greater or leſs, not exceeding a Semi-circle, would be perform'd in the ſame Time, and therefore the greater Arch would in this Caſe, require the greater Motion; but when it ſwings in the groſs Air, the Reſiſtance of the Medium deſtroys the Equilibrium; becauſe the ſwifter Motion of the ſame Body in the ſame Fluid, is more reſiſted than its ſlower Motion; therefore the ſame Pendulum, keeping the ſame length, muſt vibrate quicker in a leſſer Arch than in a greater: Conſequently, when the Oyl is coagulate in cold Weather, the Beats of the Clock for every Swing, to which the Motion of the Index anſwers, muſt be more in the ſame Time; that is, the Clock muſt then go faſter, and in hot Weather, for a contrary Reaſon, ſlower.

THE lengthening and ſhortening of the Pendulum by Heat and Cold is of no Conſideration in this Place, becauſe the diſtinct Variations on what Cauſe ſoever they depend, are diſtinctly accounted for.

FROM this it may ſeem ſtrange, that the Clock ſhould not be diſpos'd to go faſter; for the Continuance of the Oyl in the moving Parts, than when it is firſt clean'd, but Experiment doth not anſwer, whatever be the Reaſon of it, which I ſhould ſooner gather from the Experiment than make that an Objection againſt this, and therefore I muſt let it go with this ſingle Reflection, That probably the perpetual working of the Oyl, by the Motion of the Clock, may make it the more lubricous.

AS for this laſt Variation, I found it neceſſary to diſtinguiſh it into two Parts, though it wholly proceeds from the ſame immediate Cauſe, that I might with leſs perplexity, conſtruct the following Tables, the one anſwering the regular Viciſſitude of the Seaſons Yearly, the other depending upon the uncertain Changes of the Weather: But obſerve, That in Summer-time, foul Weather is generally accompany'd with ſome Degrees of Cold, and therefore muſt go under that Denomination; and in Winter Warmth and Cold is more eaſily diſtinguiſh'd, whether the Seaſon be foul or fair. Hence we have three Variations of the Clock from equal Time to be diſtinctly accounted for in theſe Tables; The firſt is to be found by the Day and Month of the Kalendar; the ſecond by the Diſtance of the Time preſent from the Time of Cleaning; the third by an Account kept of the Changes of Weather, which for common Purpoſes may be in ordinary neglected, ſince it is ſo ſmall, except when the Weather proves for a long Time ſettled, and may eaſily be remember'd.

THIS Hypotheſis will increaſe the Number of Tables, neceſſary for adjuſting the Motions of the Clock. Mr. *Flamſtead* has already given us two, which, though they are very helpful, yet ſince they were not Originally deſign'd for this Purpoſe, may be allow'd to vary a ſmall matter from the Truth, I here ſpeak of; but to ſpeak properly, theſe are only Tables of the Equation of Time, ſhewing the Sun's Variation from Equal Time; but the Clock itſelf doth vary from Equal Time, as well as the Sun, and therefore they are wrong apply'd, when they are uſed to Determine the Variations of the Clock from the Sun, though they are perfectly true and exact of themſelves, within a ſmaller matter than can be diſcern'd by the beſt Inſtruments, as the Sequel doth abundantly prove. Now ſince theſe Tables of his, the one anſwering and ſhewing the Inequalities of the Sun's Right Aſcenſion for equal Parts of the Ecliptick, the other the Inequalities of the Sun's Elliptical Orbit, reduc'd to a Circle, do both Meaſure the ſame Period, that is, the Annual Revolution of the Sun, they may be, and are very well compounded or made into one, So the firſt of theſe Variations of the Clock from equal Time, ſerving for the ſame Period, I thought it would be beſt, both for ordinary and ſpecial Uſe, to engroſs them, for avoiding a multiplicity of Calculations to the ſame Purpoſe, ſo that the Compound Table, thence ariſing, will ſhew the Clock's Variation from the Sun, which is the common Index of Time.

FROM the Premiſes it appears, that theſe three Variations cannot conveniently be brought into one Table, and therefore muſt be diſtinctly accounted for; becauſe the firſt is Periodical and Circular; the ſecond Progreſſive; the third Unſettled, or depending on a variable Cauſe: However, ſince the firſt is accommodate to the ſame Period, as the Table of Equation of Natural Days; both theſe may be conveniently Compounded, that is, Mr. *Flamſtead*'s Tables, and the Table of the firſt Variation: And ſo three Tables are ſufficient to ſhew all the Variations of the Clock from the Sun at any Time, and in any Variety of Weather.

ACCORDINGLY, the three following Tables are Calculated in ſuch a Method, as to ſerve not only for common Uſe, but for the niceſt Aſtronomical Purpoſes; and therefore, for the Satisfaction of the Curious, it will be requiſite, after I have given the Tables themſelves, to Note ſome Things in relation to the Obſervations upon which they are founded, as alſo the Method of their Conſtruction and Uſe.

A TA-

A TABLE of the CLOCKS Variation from

Day.	January	Feb.	March	April	May	June
1	9 0′	16 22′	12′ 39′	3′ 46″	1′ 23″	0′ 51″
2	9 27 too faſt	16 23 too faſt.	12 24 too faſt.	3 29 too faſt	1 26 too ſlow	1 1 too faſt.
3	9 53	16 24	12 8	3 13	1 28	1 12
4	10 18	16 23	11 52	2 59	1 30	1 22
5	10 42	6 22	11 35	2 44	1 31	1 32
6	11 5	16 19	11 18	2 29	1 31	1 42
7	11 27	16 17	11 1	2 14	1 31	1 52
8	11 49	16 14	10 45	2 0	1 30	2 3
9	12 9	16 9	10 28	1 46	1 29	2 14
10	12 28	16 4	10 11	1 32	1 28	2 24
11	12 48	15 58	9 54	1 19	1 27	2 34
12	13 7	15 52	9 37	1 6	1 24	2 44
13	13 25	15 45	9 19	0 54	1 21	2 54
14	13 42	15 38	9 2	0 43	1 17	3 5
15	13 58	15 30	8 44	0 32	1 13	2 15
16	14 13	15 21	8 26	0 21	1 8	3 24
17	14 27	15 12	8 8	0 10	1 4	3 34
18	14 41	15 2	7 50	0 0	0 59	3 43
19	14 54	14 51	7 32	0 9 too ſlow.	0 53	3 52
20	15 [illegible]	14 40	7 14	0 18	0 47	4 1
21	15 17	14 29	6 56	0 26	0 40	4 10
22	15 27	14 6	6 37	0 35	0 34	4 19
23	15 36	14 4	6 19	0 43	0 26	4 27
24	15 44	13 51	6 1	0 50	0 18	4 35
25	5 52	13 37	5 44	0 56	0 10	4 42
26	15 59	13 24	5 27	1 2	0 2	4 50
27	16 5	13 10	5 9	1 7	0 6 too faſt.	4 57
28	16 10	12 54	4 52	1 11	0 14	5 3
29	16 14		4 35	1 15	0 23	5 9
30	16 17		4 19	1 19	0 33	5 14
31	16 2		4 3		0 42	

the SUN ſerving for the 2d after LEAP-YEAR.

Days	July	Auguſt	Sept.	Octob	Novem	Decem
1	5 19′	3′ 35″	5′ 44′	15′ 34″	17′ 30	7 0″
2	5 23 too faſt.	3 22 too faſt.	6 6 too ſlow.	15 48 too ſlow	17 20 too ſlow	6 29 too ſlow.
3	5 27	3 10	6 28	16 2	17 10	5 58
4	5 3	2 57	6 50	16 16	16 59	5 27
5	5 34	2 44	7 11	16 28	16 46	4 56
6	5 37	30	7 33	16 40	16 33	4 24
7	5 40	2 15	7 54	16 51	16 20	3 52
8	5 42	1 59	8 16	17 1	16 5	3 19
9	5 43	1 43	8 38	17 11	15 49	2 47
10	5 43	1 27	9 0	17 21	15 33	2 15
11	5 43	1 11	9 22	17 30	15 16	1 43
12	5 43	0 55	9 43	17 38	14 57	1 11
13	5 42	0 38	10 4	17 45	14 39	0 40
14	5 41	0 20	10 24	17 51	14 19	0 9
15	5 39	0 3	10 45	17 56	13 58	0 23
16	5 36	0 15 too ſlow.	11 5	8 2	13 37	55 too faſt.
17	5 32	0 33	11 26	8 6	13 15	1 28
18	5 28	0 52	11 46	18 9	12 53	2 0
19	5 23	1 11	12 7	18 12	12 29	2 32
20	5 18	1 31	12 26	18 14	12 5	3 4
21	5 13	1 52	12 46	18 15	11 40	3 36
22	5 7	2 12	13 5	18 16	11 15	4 7
23	5 0	2 32	13 23	18 15	10 49	4 37
24	4 53	2 53	13 42	18 13	10 22	5 7
25	4 45	3 14	13 59	18 10	9 54	5 37
26	4 37	3 35	14 16	18 7	9 26	6 7
27	4 28	3 5	14 33	8 3	8 58	6 37
28	4 19	4 17	14 48	17 59	8 30	7 6
29	4 9	4 38	15 4	17 53	8 1	7 34
30	3 58	5 0	15 20	17 46	7 31	8 3
31	3 47	5 22		17 39		8 31

A TABLE for the Variation of the Pendulum.

N°. I. Firſt Length.			N°. II. Second Lengh.		
Time after Cleaning the Clock.		Variation.	Time from Cleaning the Clock.		Variation.
Mon.	Days	2′ Slower.	Mon.	Days	
1	29	1	14	438	2′ Slower.
2	64	0	15	467	1
4	109	1 Faſter.	16	502	0
7	219	2	18	547	1 Faſter.
11	329	1	21	657	2
12	374	0	25	767	1
13	409	1 Slower.	27	812	0
14	438	2	28	847	1 Slower.
			29	876	2

A TABLE for the Variation of Weather; Shewing in Decimals of a Second the Clock's daily Variation anſwerable thereunto.

	Cold	Warm	
January	0,8	1,8	December
February	0 9	1,7	November
March	1,1	1,5	October
April	1,5	1,1	September
May	1,7	0,9	Auguſt
June	1,8	0,8	July
	Faſter	Slower	

THESE Tables are mainly founded upon Experiment, which, tho' it is leſs exact than Theory, yet generally yields us the moſt Satisfaction, eſpecially in Things of ſuch a Nature, as the Subject of the preſent Enquiry: Therefore, that they may be as uſeful as I can make them, and conſidering that they will be ſerviceable to more Purpoſes, than what is under Conſideration at preſent, it will be requiſite that I ſhould ſatisfy the Reader in ſome Things relating to the Foundation, Conſtruction and Uſe of theſe Tables, each of them in their Order briefly.

AS to the firſt Variation, the Reſult of my Obſervations was this; That in Summer the Clock lost [redacted] of Equal Time about 5 Minutes, and 20 Seconds; G and in Winter [redacted] gai as much, when duly rectify'd; of which that I might be throughly Satiſfy'd, I made as many Tryals, as I think prove the Truth of it, beyond a Poſſibility of any conſiderable Error, all of them concurring in the ſame Concluſion.

THE Daily Variations are not always equal; for at one Seaſon of the Year, they are ſo ſmall, as ſcarce to be diſcern'd for a conſiderable Time together, and at other Times very ſenſible in a ſhort Time. Now, ſince I am proceeding in an untrodden Path, I take the Liberty to borrow, and accommodate a few Terms of Aſtronomy to Things that have a near relation to their original Signification; particularly the two oppoſite Points of the Year (if I may ſo call them, comparing this Period to a Circle) where the Variation is greateſt, I call the Tropicks; thoſe are the 7th of *July*, and the 6th of *January*; and the Quadratures or intermediate Points, I call the Equinoxes, thoſe are the 7th of *April*, and the 7th of *October*. At the Equinoxes the Clock anſwers the Tables of the Equation of Natural Days, without any Variation at all of the firſt Sort; but at the Tropick it loſeth in Summer, and gains in Winter, about 3 Seconds daily, which in the Space of 3 or 4 Weeks may be eaſily diſcern'd.

THIS Daily Variation increaſeth from the Equinoxes to the Tropicks; and decreaſeth from the Tropicks to the Equinoxes; but in what Proportion, is a material and difficult Queſtion to, determine; becauſe the daily Difference is too ſmall to be diſcern'd by the niceſt Inſtrument: However, I found, by comparing Obſervations, made at equal and pretty large Intervals of Time, that the Ratio of the Series was a Medium betwixt that of the Daily Differences of the Tangents of the Meridian Altitudes, (which give the Denſity, or rather Frequency of the Sun's Rays Daily, and therefore are a juſt Meaſure of his Heat, upon which this Variation depends, though not for the whole of every Day, but only in that Poſition,) and that of the Daily Difference of the Length of Day, yet ſo as to come nearer the latter, than the former.

UPON this Hypotheſis, I firſt collected all the daily Variations of the Clock from Equal Time into a Table for one Quarter of a Year from the Tropick to the Equinox, which is as follows:

30	30	28	26	23	20	17	14	11	8	4	1	2	5
30	30	28	26	23	20	17	14	10	7	4	1	2	6
30	30	28	25	22	19	16	13	10	7	4	0	3	6
30	29	28	25	22	19	16	13	10	6	3	0	3	6
30	29	27	25	22	19	16	12	9	6	3	0	4	7
30	29	27	24	21	18	15	12	9	6	2	1	4	7
30	29	27	24	21	18	15	12	8	5	2	1	4	8
30	29	26	24	21	18	14	11	8	5	2	2	5	&c.

THESE are the Daily Variations of the firſt kind expreſs'd in Decimals of a Second for the Eaſe and Exactneſs of Calculation in conſtructing the Tables; for if the Fraction was omitted, either the whole Account would be falſe, or the Series irregular, diſproportionable and obſcure.

THE firſt 91 Places ſerve for every Quarter of the whole Period, reckon'd from each Tropick both backward and forward; but the Account is continu'd a little farther, not only to ſhew the regular and equal Increaſe and Decreaſe of the Variation progreſſively from one Denomination to the other, *i. e.* from faſt to ſlow, on each ſide the Equinoxes, but eſpecially to Note one Singularity, in which the Tranſits at the Equinoxes differ; for at the Vernal Tranſit the middle Cypher, ſeparated by two Lines from the reſt of the Account, is to be omitted; but at the Autumnal added, that ſo the whole Period may conſiſt of 365 Diviſions anſwerable to the Number of Days in a Year. This Order doth in the firſt Caſe ſuit well enough with the regular Proceſs of the Numbers, to a good Diſtance on each ſide the Equinox, allowing the Proceſs ſhould be ſomething ſwifter at the Tranſit than at a Diſtance; and in the latter Caſe the Order is exactly the ſame, as appears by Inſpection. However, the vacancy of a ſingle Place, is no conſiderable breach of Order, amongſt ſo many very ſmall Fractions.

From this Series of Numbers muſt the Equation be collected, which gives for every Day in the Year the Difference betwixt the Clock and Equal Time; which Equation is the Difference betwixt Mr. *Flamſtead*'s Compound Table and the firſt of theſe three above given. This being conſider'd, it will appear, that if theſe two Tables be brought as near to each other, as they can be, that they will coincide in two Places at leaſt, which I ſhall call for Diſtinction, the Points of Coincidence. Now as for matter of Truth, it is indifferent where theſe (Points of Coincidence) be fix'd, provided, the Equations increaſe and decreaſe to and from theſe Points of Coincidence, as the Variations, which are fix'd and invariable, require; for the Motion of the Clock, when rectify'd, will be the ſame, whether it be ſet to Equal Time at this or another Seaſon of the Year, and therefore the Conſtruction of the Tables ſuppoſeth the Coincidence to be at ſuch a determinate Point, and the Clock ſet anſwerably; but as to matter of Convenience, it is not altogether indifferent, where the Points of Coincidence are fix'd; for this requires it be ſo order'd, as that the utmoſt Variations from the Sun of each Denomination may be as little as is poſſible, that is, as nearly equal as may be, and alſo that the number of Variations on each ſide be nearly equal; but if theſe be inconſiſtent, that a Medium be kept betwixt both. This is the general Rule; but there is a particular Conſideration, which will throw us off the Medium a little; for it ſo happens, that in one Place the Variation riſeth to ſo very ſmall a quantity, that if the firſt part of the Rule be ſtrictly obſerv'd, and a Table extracted from this, giving only the whole Minutes, and their correſponding Times; for common Uſe, this would ſeem to an incautious Eye, an Error in the Conſtruction of the Table, and ſo be occaſion of Scruple or Miſtake in the Uſe of it, when it is obſerv'd, that the Variations return under the ſame Denomination; nay, (which would be more perplexing) there would be three Returns in the ſame Denomination, for one in the other; and even as it is, it appears at a curſory View, unequal and irregular enough already. By theſe Cautions I was directed to the propereſt Point for Coincidence, which happens at the Beginning of the Year preciſely; ſo that the firſt Day in the Year, is the firſt in the Table, which receives an Equation. But before theſe Equations can be duly affix'd to the Table of equal Time, it is to be noted, that one Year is not a compleat Period, but four, becauſe of the intercalary Day of every Leap-Year, and yet the Difference hence ariſing, betwixt one Year and the next, is ſo very inconſiderable, and altogether inſenſible, if the Variation of the 3d Sort be rightly Conſider'd, that I choſe to make the Table ſerve for one common Year only, rather than multiply it into four: And upon this Conſideration, the 2d after Leap-Year is the fitteſt; therefore, ſince the ſingle Table of Equal Time, for one common Year, does not preciſely return into itſelf, *i. e.* the Beginning and the End do not anſwer: Therefore ſome Allowance muſt be made for this Inequality, and the Table brought into a circular Form, before it can be engroſs'd with the Variations of the Clock. This Alteration will not make it the leſs ſerviceable, either for common or extraordinary Purpoſes, if in the Uſe of it this Rule be obſerv'd, (by ſuch as would come to a greater Exactneſs than may be had by Inſpection) that the Variations for the Leap-Year on any Day given is almoſt equally betwixt the Variation in the Table for the given Day and the Day foregoing, after Intercalation, or following before Intercalation, or thus, the Difference betwixt the given Variation and the True is about half the Difference betwixt that and the next following, till the 29th of *February*, or foregoing all the Year after, to be added or ſubtracted, as the Numbers are decreaſing or increaſing progreſſively: So alſo for the firſt and third after Leap-Year, the Difference betwixt the given Variation and the True, is about a quarter of the Difference betwixt that and the foregoing in the former Caſe, to be added; or the following in the latter Caſe, to be ſubtracted, as the Numbers decreaſe or increaſe progreſſively.

THE Daily Variation of the Clock from Equal Time, is the daily Difference betwixt the true Space of a Day, by an equal Diviſion of Time and the Motion of the Clock, which is the aſſign'd Meaſure of a Day, which by the foregoing Table appears to be at one Time more, at other Times leſs, and ſometimes equal; ſo that it differs by a Degree of Motion anſwerable to this Variation and conſequently the Difference betwixt the Report of the Clock and the true Time of the Day, muſt be Daily increaſing or decreaſing, in a Proportion anſwerable to the Daily Variation, Theſe two are carefully to be diſtinguiſh'd: The firſt, *viz.* the Difference of the Clock's Motion and the Space of a Day, I call the Clock's Variation from equal Time: But the ſecond, *viz.* The Difference betwixt the Clock's Report and the equal Time of the Day is the Clock's Equation, which laſt is found by continual Addition or Subtraction of the Variations, according to their Denominations to or from each other Daily, beginning at the Coincidence, and proceeding forward in the Courſe of the Year: As for Example, Suppoſe at the Entrance of the Year the Clock be duly rectify'd to equal Time, by the Tables of the Equation of Time; then for the firſt Day the Variation is 30 Decimals of a Second ſwifter, for the ſecond Day 30 more, &c. then at the End of the Work the Equation will be 21.0, that is the Difference betwixt the Clock's Report and equal Time, or the Clock will be 21 Seconds too faſt. After the ſame Method the Equations for every Day in the Year are Collected from the Table of the Simple Variations laſt given, obſerving, that from one Equinox to the other the Variations are of the ſame Denomination, that is, to be all added or all ſubtracted from each other; but after the Tranſit, they are of contrary Denomination, and therefore, where the former were added, the following muſt be ſubtracted, then, having gain'd the Equations for every Day in the Year, they are to be ſingly engroſs'd with the Equations of Natural Days, or Differences of the Sun from equal Time, obſerving the ſame Rule, that where thoſe are of the ſame Denomination with theſe, their Sum, (but if otherwiſe their Difference) is the Variation of the Clock from the Sun, which make the firſt Table here given.

THE ſecond Variation, depending on the different Temper of the Oyl, is continually progreſſive, and not returning, and the Time given in the Table for finding this Variation, muſt be reckon'd from the time of the Clock's being clean'd or well dreſs'd; for from that Time forward it will be continually loſing, if the Pendulum have the ſame length, as at its firſt Cleaning is requir'd for a Motion anſwering to equal Time, which, for the following Reaſon, it is ſuppos'd not to have. To preſerve the Clock from any ſenſible Variation of this kind, it would require a continual Alteration of the Pendulum, which would be inſufferably tedious and uncertain; therefore Convenience requires us to aſſign a certain Length to the Pendulum, which may ſerve for a conſiderable Time together, and give the anſwerable Variations for that Length, which therefore ſhould be ſuch a Length as the equable Motion of the Clock requires, at the middle of that Time which therefore I ſhall call the Equilibrium; ſo that from the firſt beginning of the Motion, or at its firſt ſetting-out after cleaning, this Length of the Pendulum is leſs than what it then requir'd; and therefore the Clock muſt be continually gaining, or go too faſt till the Time of the Equilibrium; which, when it has paſs'd, it will loſe as much in the ſame Time; after which, the Variation will be what it was at firſt; then if the Pendulum be alter'd to the ſecond Length, it will have nearly the ſame Effect, I do not ſay [exactly] which though in Theory it will appear to be ſomething, is in Fact inconſiderable; nay, altogether inſenſible. Theſe two Lengths, ſpecify'd in the Table, will carry the Clock above two Years, in which Time it will need Cleaning again, tho' kept ever ſo cloſe; for which Reaſon, I have gone no further, but mark'd the Lengths in the Tables thus, N° I. N° II. which divides it into two Parts, each ſerving for a diſtinct Period, both reckon'd from the time of Cleaning.

IT is to be noted, That this Variation is the varying the ſwiftneſs of its Motion by equal Degrees, accounted from the Equilibrium on each ſide, both backwards and forwards, which, by examining Experiments, I found to be one Centeſm of a Second Daily; ſo that ſuppoſing the Clock at the Equilibrium to be free of all Inequalities, the firſt Day following it will go one Centeſm ſlower, the next two, the third three; conſequently, the Difference betwixt the Clock's Report, and the equal Time of the Day, at any aſſign'd Space from the Equilibrium, will be the Aggregate of all the intermediate daily Variations, or differences of Degrees of Motion, for the firſt Day $\frac{1}{100}$ too ſlow, the next as much, if for that Day it had kept pace with equal Time; but ſince the Motion hath decreas'd two Degrees more, the Equation will be three for the ſecond Day, and for the like Reaſon, ſix for the third, ten for the fourth, *&c.* therefore equal Periods give unequal Equations; but Convenience requires, that the Equations given be made equal, and then the Periods will be unequal: The Equations need not here be given in leſs quantity than a Minute, becauſe the obvious Ratio of the Series, will make out the intermediate Equations, the Periods anſwering the Equation given, increaſe and decreaſe, to and from the Equilibrium progreſſively, in the Proportion of the following Numbers, 110. 45. 35. 29.

BY the Premiſes it appears, That this utmoſt Variation, in the Space of 219 Days, will be but four Minutes, and the Difference betwixt this and the firſt Table ſtill leſs, *i. e.* half as much, ſuppoſing the Clock to be ſo ſet, as that the Coincidence of theſe two Tables fall in the middle Time betwixt its firſt ſetting-out and the return or Equilibrium; by this Means the Clock is kept as near the Sun as it is poſſible.

EACH Period is expreſs'd not only in Days, but in Months, yet both ſerve for the ſame Purpoſe, only the latter will be readier for common Uſe, in which the preciſe Number of Days may uſually be neglected.

These Variations here given, anſwer to the aſſign'd Lengths of the Pendulum, which is ſuppos'd to be vary'd in the ſame Place at different Times, reckon'd from the Cleaning, which Variation of the Pendulum, being the Foundation of the Table, is the Reaſon of the Title.

But it is to be noted, That the ſame Lengths will not ſerve in different Latitudes, as by Authors is generally obſerv'd; I have not myſelf made Obſervations in any other Latitude, but that of my preſent Reſidence, which is 53 Deg. 22 Min. but I have obſerv'd one Thing, which may be worth Notice in this Place, That the Length which ſeem'd to be mark'd by the Maker of the Clock, for the Latitude of *London*, and which no doubt was Adjuſted by a Regulator, was about $\frac{1}{10}$ of an Inch different from the 2d of thoſe Lengths given in the Table; for this Reaſon I cannot give the Lengths abſolutely and univerſally; and indeed need not, for they are beſt found by Obſervation at ſeveral Eſſays (for which two are ſufficient) thus, Having found the Time of the Day exactly, either by the Quadrant, or any other Inſtrument for the Purpoſe, obſerve how the Clock is then with regard to the Sun; thence at ſome diſtance of Time, make a ſecond Obſervation, remarking how much the Clock hath gain'd or loſt of the Sun, more than all the Tables together give for that Interval, then by the following Proportion, the due Alteration of the Pendulum may be found. As the given Length in any Number of Aliquot Parts: is to the Square of the Number of Vibrations in the Interval:: ſo is the juſt Number of Vibrations for that Interval requir'd: to the juſt

Length of the Pendulum; then by adding or ſubtracting (according as it goes too faſt or too ſlow) the juſt Length of the Pendulum thus found, to or from the preſent Length, the Difference is the Alteration of the Pendulum requir'd; where obſerve, That the preſent Length need not be very nicely determin'd, for finding the Alteration, becauſe an abſolute Length to the Alteration, if it be any whit near Truth, is vaſtly diſproportionable: But if this Method do not pleaſe, there is an eaſier ſtill, which will come within an inconſiderable matter of Truth, that is, by a third Obſervation at a ſecond Interval of Time; Having immediately after the ſecond Obſervation alter'd the Pendulum at adventure, obſerving how much, and comparing the Motion of the Clock for both Intervals, then the Alteration requir'd will be given very near to Truth, by this Proportion, if the Intervals of Time be equal. As the Difference betwixt the Motion of the firſt Interval or Period and the ſecond: is to the Difference betwixt the ſecond and the true Motion requir'd:: ſo is the firſt Alteration of the Pendulum: to the further Alteration requir'd.

THE Alterations of the Lengths are to be made anſwerable to the Motions; ſhorter Lengths to ſwifter Motions, and contrariwiſe; whether Progreſſive or Intermediate. If the Bob or Weight of the Pendulum be ſupported by a Screw, the Lengths are beſt reckon'd by the Revolutions of the Screw; one Example will make the Thing plain.

SUPPOSE the Clock appears by Obſervation, when it is firſt clean'd, and well oyl'd, to loſe 10

Minutes in a Week, more than the Tables allow for the Time given; and at the end of that Time, be ſcrew'd up at adventure $\frac{3}{12}$ of a Revolution, or a fourth part; then at the end of the next Week, it be obſerv'd to have loſt four Minutes in that Time, then I ſubtract four from ten, for the Difference of the Motion in each Interval, which leaves ſix, and take the four for the Difference of the Motion of the ſecond Interval from Truth, and ſay,

As 6 is to 4 : : ſo is 3 to 2 : : Theſe two twelfths of a Revolution, is the ſecond Alteration requir'd; therefore if the Pendulum be ſcrew'd up $\frac{2}{12}$ more, it is right. This Method of finding the Lengths by ſeveral Eſſays at adventure, is no diſparagement to the Thing, nor leaves it at Uncertainty; becauſe the Lengths being once found, will always ſerve, and the regular Motions of the Clock, being aſcertain'd in the Tables, the abſolute Lengths are ſoon ſtated for any Place by the foregoing Experiment, better than by an abſolute Meaſure; becauſe they are variable in different Latitudes. However, it may be ſome Help to Note, That the difference of the Lengths in this Latitude of 53°. 22′, is $_{250}$ of an Inch.

THE third Variation will be of ſmall Uſe for common Purpoſes in ordinary, except when the Weather proves ſettled for a long Time together; yet it will be of great Service in Aſtronomical Obſervations, for duly adjuſting the Lengths of the Pendulum at firſt, in which it ſhould by no means be neglected; as alſo it will give Satisfaction in the Truth of the Premiſes, but eſpecially it will be a great Help towards Correcting and Determining the Inequality of an ordinary Pocket-Watch, depending upon the like Cauſe, and promiſeth fair for Meaſuring the Longitude thereby, and therefore I ſhall ſay ſomething of it in this Place.

THIS Variation depends upon the ſame immediate Cauſes as the firſt, *viz.* Heat and Cold; but theſe Cauſes themſelves, being differently affected by others more remote, and abſolutely diſtinct, the immediate Cauſe muſt vary in Degrees of Efficacy, as the more remote do concur with, or counter-act each other; and therefore the ultimate Effects muſt be diſtinguiſh'd, according to the difference of the firſt Cauſes, if their Effects be duly accounted for; and therefore the firſt Table cannot be engroſs'd with the third; for the remote Cauſe of the firſt Variation, is the Sun's regular Approach to, and Receſs from the Place of the Recipient Subject; but in adjuſting and proportioning the Effect to his Influence, ſome Regard muſt be had to his gradual Operation upon the Recipients, according to their different Natures ſeverally, and their mutual Habitudes reſpectively: As for Inſtance; The Sun in the ſame Poſition to the Plain of the Horizon will have leſs Effect upon the Air and Soil, or make a leſs Drought at firſt, when both are ſated with Vapours, than after a While, ſhould he continue in the ſame Station. The like Effect he will have upon Vegetables and other Things, as particularly the Clock; and though different Subjects will receive and loſe the Effects one ſooner than another, yet herein they will have ſome influence upon each other, and by the Proportion of the larger and more numerous, to the leſſer and fewer, the general Sympathy and State of the whole may be Determin'd; and therefore the Tropicks of the firſt Variation are conſiderably diſtant from the Natural Solſtices, in fixing of which, I was entirely directed by Experiment; but it was a great Satisfaction, on, that I found them ſo anſwerable to the various Scenes and Seaſons of Vegetables. Now the remote Cauſe of the third Variation, is the different Temperature of the Air, or the Difference of Weather; which is irregular and unconſtant; and yet the Influence of this upon the Clock may be determin'd by its Influence upon other Recipients, as particularly the Thermometer.

THESE two remote Cauſes, acting by the ſame immediate one, or rather, by the ſame Medium of Heat or Cold upon the ultimate Effect, the one is to be conſider'd with reſpect to the other, *i. e.* the one is to be reckon'd an Abatement or an Augmentation of the other; accordingly ſince each Month in the Year is diſtinguiſh'd by the firſt, and liable to both Extreams of the latter. Hot Weather is in Summer reckon'd Seaſonable, in Winter Unſeaſonable; and the contrary may be ſaid of Cold: Therefore in Summer, I call Hot Weather the concurring Extream, and Cold the contrary; but in Winter Cold Weather the concurring Extream, and Hot the contrary. This being premiſed, I ſay, That

THE Difference betwixt the Effects of both Extreams in the Motion of the Clock, is 26 Decimals of a ſecond for one Day; yet ſo, that at the Equinoxes the Allowance for each Extream is equal, *viz.* 13 Decimals Daily, and the equal Time by the firſt Tables is a Medium betwixt the two Extreams; but at the Tropicks, the Allowance for the concurring Extream is eight Decimals, and for the contrary eighteen; and at any intermediate Times the Allowance is anſwerable both to this Rule, and to the obvious Ratio of the Numbers in the Tables.

I NEED not give the Daily Variations for any intermediate Degrees of Heat and Cold, ſince the whole Range of the Thermometer in any particular Seaſon by which the Variations are to be determined, is anſwerable to the utmoſt Difference of theſe Variations, and the intermediate Degrees, to the Differences of the intermediate Variations; nay, even our Senſes are ſufficient to determine, as near as Neceſſity requires, theſe very ſmall Quantities in queſtion.

IN the Uſe of theſe Tables, take the following Directions:

TO rectify the Clock: When the Clock is firſt clean'd, and well oyl'd, ſet it not exactly with the Sun, but ſo much faſter or ſlower, as both the former Tables together direct. The ſame Rule is to be obſerv'd, when by Accident or Omiſſion the Clock has ſtood. Now it appears by the Beginning of the ſecond Table, that at the firſt after Cleaning, it is to be ſet two Minutes ſlower than the firſt Table directs at the Time given, for then it will gain, ſince the ſuppos'd Length of the Pendulum is ſuch as the equal Motion requires at the Time of the Equilibrium, that is, ſhorter than what it requires at firſt ſetting-out.

TO rectify the Pendulum: Having found by Experiment the Lengths requir'd, as above mark'd, the firſt N° I. the ſecond N° II. which is the moſt conveniently done upon the Nut, which ſupports the Weight or Bob of the Pendulum, if the difference of the Lengths do not take a whole Revolution; thus, When the Pendulum is in the firſt Poſition, ſet the firſt Figure upon the fore-part of the

Nut directly forward, or in any other quarter, that may be readily and exactly aſſign'd, and while it continues thus, follow the firſt Part of the Pendulum-Table, mark'd with the ſame Number; but when fourteen Months, or 438 Days are expir'd, ſhorten the Pendulum to the 2d Length, found as before, and ſet the 2d Figure upon the Nut on the ſame Quarter from the Center or fix'd part of the Pendulum, where the firſt Figure ſtood before the Nut was remov'd; and while it continues in that Poſture, follow the 2d Part of the Pendulum-Table mark'd with the ſame Number.

To find the Variation any Time after: Seek in the firſt Table the Month and Day current, and take out the Variation anſwering thereto, then reckon how far the Day current is diſtant from the time of Cleaning, (before chalk'd on the inſide of the Caſe, or elſewhere, to be ready for Uſe,) and for the Number thus found, take out the anſwerable Variation in the 2d Table, and if both theſe Variations agree in the ſame Denomination, *i. e.* both ſhewing the Clock too faſt, or both too ſlow, their Sum, if otherwiſe, their Difference, is the abſolute Variation of the Clock from the Sun: but to be further Corrected by the 3d Table, thus; Recollecting the general Temperature of the Air, ſince the Time of its being laſt ſet, either by a conſtant Account kept, or by Memory, (which for common Uſe will ſerve) for every Month diſtinct, reduce all the Variations of the Weather for each Month to a Medium, and for each, take out the Variation from the middle Column anſwering; that multiply by the number of Days in the Month, ſetting down the Products orderly, under their proper Denominations, in two Columns ſeverally, which collect into one Sum; ſubtract the leſſer from the greater, and their Difference is the Variation of the third kind, and take its Denomination from the greater Part, which being added to or ſubtracted from the Variation above, is the Variation ultimately Correct, and takes its Denomination from the greater Part.

It is ſcarcely poſſible to determine, what Caſualties ſuch Contrivances, as I have hitherto mention'd, may be obnoxious to, before Tryal hath been made of them; and therefore, how far they may be effectual to the Purpoſe deſign'd, or what Charge and Trouble they may put upon the Peruſers, I leave to their impartial Judgment, which cannot be much. However, ſince theſe Propoſals perhaps will be differently receiv'd, and various Opinions and Cenſures of them will be paſs'd, it is my Part to carry the Search as far as I can, and propoſe as many Expedients, as to me ſeem likely to anſwer our preſent Expectation, that the Readers may be at Liberty to Chuſe, or make Tryal of which they like beſt: And therefore I ſhall proceed to enquire, What further Advantages Nature will afford us within our Liquid Province, towards a regular Movement? And particularly, Whether we have here any Power or Principle of Motion, which either is uniform in itſelf, or may be reduc'd to a Conſtancy and Equality? And I think there is one, that is, the Wind.

This, however irregular it may ſeem to be at the firſt Thought, may be made very ſerviceable in Meaſuring Time; and if ſo, it is the properest Means that can be apply'd, becauſe in long Voyages it is the only Conveyance; and we are ſecure of it, as long as we ſhall need the exact Meaſure of Longitude, for which this Movement is deſign'd;

for as ſoon as the Wind ceaſeth, or the Ship is becalm'd, ſhe muſt lie by, and not alter either her Longitude or Latitude; conſequently, if her Longitude can by this Means be determin'd, at the Station, where ſhe happens to lie by, the difference of Longitude, after ſhe begins to ſail again, may in the ſame manner be found.

FOR this Purpoſe, the Engine propos'd muſt be ſo contriv'd, that the unequal force of different Blaſts may be corrected, and their Effects upon the Movement be always equal. This may be effected two Ways, both which will be in this Caſe neceſſary. Suppoſe the Inſtrument be furniſh'd with Sails, like thoſe of a Wind-mill, upon four or ſix croſs Spokes, Turning in a Plane, perpendicular to the Courſe of the Wind; let the Poſture of the Sails be oblique to this Plane, in an Angle, that may anſwer to the Breadth of each Sail, and the intended Motion; in determining which, this Rule is to be obſerv'd, If the Width of the Sails bear a large Proportion to their Diſtance, and the Length of the Radius, with Deſign to make the beſt Advantage of the leaſt Gale, then the moſt convenient Poſture for the Sails, is, at an Angle of 45 Deg. with the Courſe of the Wind: But if Things be ſo order'd as to require a rapid Motion, with a brisk Gale, and yet ſmall Sails, for fear of violent and ſudden Blaſts, then the Angle of the Sails to the Courſe of the Wind, ſhould be leſs acute, betwixt 50 and 60 Deg. more or leſs, as the Motion is intended to be ſwifter or ſlower; and therefore it will be convenient to have three or four Setts to be ſlip'd upon the end of their Axis, and changeable, as Occaſion requires, *i. e.* as the Wind blows harder, or more gently. Each of the Spokes, bearing a Sail, ſhould be made to turn in a Socket, furniſh'd with a Spring, to keep the Sail in its Natural Poſture, and by giving way in every violent Guſt, to let the Sail fall nearer the Wind; by this Means it appears, that the Inequalities of the Wind would be much corrected; for the Sail ſtanding oblique to the Wind, is forc'd ſideways, which if it ſtood perpendicular, would be indifferent to either Side and if parallel, would ſuffer no impulſe: Conſequently, the leſs oblique it ſtands (which, in this Order, is when the Wind blows hardeſt) the leſs force it will have upon the Sail, and ſo preſerve the Motion pretty near an Equality. But yet this alone muſt not be depended on, for two Reaſons; firſt, It will be an hard matter ſo to form and fix theſe Springs, as not to bear more in one Poſture than another; whereas, if the Springs bear the whole force of the Wind, the ſwiftneſs or ſlowneſs of the Motion, will always be anſwerable to the ſtreſs laid upon the Springs, and therefore be ſomewhat unequal ſtill; ſetting aſide all other Conſiderations; for in the Communication of Motion, whatever Medium bears the whole ſtreſs of the Power, the Motion thereby communicated, is anſwerable to that Streſs, as in a like Caſe may be made plainer; If a Man in a Boat, pulls by the Oar or a Rope the Boat to Land, the Motion of the Boat entirely depending on the Strength he puts to, will be anſwerable to the Streſs he lays upon the Oar or Rope. But yet, in our Caſe, there muſt be ſome Abatement of this Inequality, for this Conſideration; The whole Force of the Wind, impreſs'd on the Sail, is not ſpent in the vertical Motion of the Sail, becauſe of its Obliquity, which gives it a Tendency forward, as well as ſide-ways more or leſs according to the Angle; and therefore ſince the leſſer Obliquity bears the leſſer Tranſverſe Impulſe, though in that Poſition the Springs exert themſelves more, bearing the whole Force of the Wind; yet the vertical Motion will not be fully anſwerable, becauſe they bear the Direct, as well as Tranſverſe Impulſe. Secondly, When the Sails are in their natural Poſition, every Gale of Wind that hath leſs ſtrength than the Springs, ſhould be conſtant and equal, (which cannot be expected) or elſe the Motion will be unequal.

These Things conſider'd, we muſt have another Contrivance to reduce the Moving Power to an Equality, which may be done by an Artificial Wind, (if I may ſo call it) excited by the Natural, or by imploying the foregoing Expedient to pump the Air from one Veſſel to another, thro' a Paſſage that ſhall be conſtantly the ſame, there to drive a ſecond Sett of Sails, (the firſt Movers) of a Movement, which will be regular, provided this Force be always alike, which might be made ſo, by what follows:

It is to be conſider'd, Whether the Pumping of the Air ſhould be perform'd by a Force-Pipe, as in Water-Engines, or with an Inſtrument in Form of an ordinary Pair of Bellows? I believe, the latter will ſerve well enough, and be better manag'd, though not ſo durable. Theſe Bellows ſhould be four in Number, ſo rang'd along the Axis of the Sails, furniſh'd with Cogs, that they may preſs, or work the Bellows, as they turn round. The Bellows muſt be coupled into Pairs by a Balance common to two; ſo that as the one falls, the other may riſe; and the Cogs plac'd quarterly round the Axis in this Order, every Cog in its ſeveral Round or Circle over againſt its proper Stop of the Bellows, to which it belongs, that each Cog may fall upon one Stop only; two Cogs, belonging to the ſame Pair, fix'd in oppoſite Points of their ſeveral Rounds, to work Alternately, and the other two likewiſe, but at Right Angles with the former; ſo that one Pair may begin to work, when the other hath half done; by this Means, the common Blaſt will be nearly equal, and continual; which therefore muſt be empty'd into one common Pipe, capacious enough to receive, without any conſiderable Force or Streſs, all the Air that comes at once. I need not be particular in deſcribing the Bellows themſelves, further than to Note, that each Piece muſt have two Valves, one to receive, the other to diſcharge the Air, both opening the ſame way, according to the intended Courſe of the Air. Let the Force-Pipe empty itſelf into one common Receiver, of any convenient Form, but ſuppoſe it be cubical, then let the upper Part or Lid of the Receiver be moveable upwards and downwards, with a conſtant Weight annex'd; the Motion being directed Perpendicular, and the Lid kept Horizontal, both by a Rabbit for the Tenons of the Lid to run in, or elſe (which is better) by a Socket, ſliding upon a Braſs Ruler, fitted to it as cloſe as the frre Motion of it will permit without any Impediment. At the Side of the Receiver, muſt be a Triangular Vent, with one Point downwards, the other two level to each other, and before it a ſliding Shut, faſten'd to the Lid, and covering more or leſs of the Vent, as the Lid riſes and falls. Then at one End of the Receiver, let there be a round Hole, conſtantly open, yielding paſſage to the Air into another Receiver, made like the former in all Reſpects. Let there be as many Receivers, as by Experiment will be found neceſſary to reduce the Wind they convey to an equal Blaſt; and at the out-let of the laſt Receiver, let the Sails of the Regular Movement be placed. Theſe Sails muſt be conſtantly the ſame, of a durable Matter, and invariably fixed to their Axis. Theſe are all the Architectonical Parts, from the firſt Power to the firſt Regulator, or equal Mover. What other *Apparatus* may be accidentally Neceſſary or Convenient, will be better deſcribed, after we have examined the Sufficiency of theſe, in each of the Particulars, and enquired, what Inequalities or Uncertainties this Contrivance may be liable to.

BESIDES the Springs of the firſt Sails, and the equal Working of the Bellows, or rather their Common Blaſt, the Receivers will no queſtion Correct all the Inequalities of the laſt Motion; for it is plain by the premiſes, that the Blaſt at the out-let of the ſecond Receiver, if both be well made, (and in regard of the Suppoſition, two are allowed) will be equal, whether it receive more or leſs Wind, becauſe always anſwerable to the Weight of the Lid, which is conſtant. The overplus of Air, more than the Out-let can deliver, being Spent at the triangular Vent, which increaſing upwards, as the Lid riſeth nearer a Stop, will encreaſe the Expence diſproportionably. This Conſideration will direct, how the Parts are to be proportioned and fitted. Firſt of all, this Triangular Vent ſhould be made anſwerable to the Capacity of the Bellows; nay, if it be wide enough to receive the whole Blaſt, when quite open, it will not be amiſs; for the Weight, which bears down the Lid, will ſink the Shut, till it diſcharge no more, than the overplus of Air, above the conſtant Blaſt at the Out-let. Secondly, the Out-let itſelf ſhould be ſomething leſs, than to tranſmit the whole Blaſt, that the Lid may riſe a little always, and the Vent be ſomewhat open; otherwiſe, if all the paſſages for the Air be conſtant, the Inequalities of the Bellows will be impreſs'd on the ſubſequent Receivers. Thirdly, For the ſame Reaſon the out-let of each Receiver ſhould gradually decreaſe, or be one leſs than another, in their Order ſucceſſively, or elſe they are of no Uſe. Fourthly, It hence follows, that ſome conſiderable Allowance may be made in fitting the Lids to the capacity of the Receivers, and the Sockets to the ſliders, for the free Motion of both in the Fall and Riſe; for, if they do loſe Wind, provided it be not the whole over-plus, it will be no Inconvenience. Fifthly, It follows hence, That either the whole Frame of the Engine, or at leaſt ſo much of it, as comprehends the Sails and their Axis, the Bellows and the Force-Pipe, ſhould be made vertical to ply to the Wind, either by a Vane, like that of a Weather-cock, or elſe with the Hand, as Occaſion ſerves, if only the mention'd Part of it be made vertical upon a Center, and be furniſh'd with a Joynt, like that of a common Water-Engine uſed to quench Fires, the Force-Pipe muſt paſs thro' the Center. Sixthly, The Size of each Part, and the Bulk of the Whole, is an indifferent Matter, provided they be made proportionably; but yet the larger they are, the leſs liable to Inequalities, by any Incident; and the leſſer they are, the more manageable, and leſs cumberſome; at a Medium, I believe, the whole Compaſs of the Engine may be brought into the Compaſs of half a Yard Cubick.

THE next Enquiry ſhould be, What Inequalities or Uncertainties it will be liable to, and how they may be Corrected. One Thing very difficult will be the right fixing the Weights to the Lids of the Receivers; for if they lie upon the Lids themſelves, it is plain, that the Engine altering its Poſture by the Toſſing of the Ship, will make them bear unequally, and thereby render all uncertain; for when they bear perpendicularly, their whole Weight is ſupported by the Subject Air; but when they lie obliquely more or leſs, they muſt accordingly more or leſs bear upon the Sides of the Veſſels which takes off from the preſſure and Force of the included Air; this Inconvenience, I think, may be wholly remedy'd by the following Means: Suppoſe each Weight be hung by a String, fix'd to the bottom of the Lid, paſſing thro' an Hole in the bottom of the Receiver, and gliding upon four ſmall Pulleys, plac'd in a Square below the Hole, but ſo cloſe as to bear it off the ſides of the Hole, the Weight being faſten'd at ſuch a diſtance below the Pulleys, as to allow the Lid its full riſe, and there left to ſwing its utmoſt Range. The Hole muſt be ſo plac'd, as that the Draught of the Pulley may be exactly perpendicular to the Plane of the Lid, along the Slider. Now let us ſee what Objections may be fairly made againſt this Contrivance.

Firſt, IT will be ſaid, That the rolling of the Ship will throw the Weights with ſuch Violence from Side to Side, that 'twill have a much greater Effect, than the ſimple and uniform Gravitation, when they hang ſtill, which, depending upon an uncertain Motion of the Ship, will render the Movement uncertain. Now, before I directly anſwer this, it is to be obſerv'd, That the Inequalities, which may ſeem to be conſiderable in the firſt Power, will be inconſiderable in the laſt Effect, and therefore an Allowance for ſenſible Cauſes of Variation, which by a ſlight Obſervation or Account of Incidents (ſuch as Streſs of Weather, or Working of the Sea, *&c.*) may be eaſily made, will not be very uncertain; for the Sails of the Movement are not the only Recipients of theſe ſuppos'd Inequalities, and therefore what they do receive hereof is in a conſiderable Diſproportion. Again, they receive the Impreſſion not only ſide-ways, *i. e.* by a tranſverſe Impulſe, which drives them round, but ſomewhat alſo directly, which is of no account in their Motion, and thus the Inequality is diminiſh'd alſo. Again, The Sails are the ſwifteſt Movers, and their Inequalities of Motion are ſtill diminiſh'd, in the ſubſequent Train; but if we examine every Thing to the bottom, we ſhall find, that this ſwinging of the Weight makes no Inequality at all; for if it doth, then it muſt riſe either from the unequal ſtreſs which the Weight lays upon the String at the Return, while it twitcheth it back again, or elſe from the Tendency of the Weight in its circular Vibration from the Center, on which it ſwings. In the firſt Caſe the Motion of the Sails from the Rolling of the Ship, cannot be more, than when it is ſtill, for, by how much the more the Weights bear at the Return, ſo much the leſs they will bear in the Tranſit, granting the Suppoſition; for whatever by checking a Motion makes it rebound, does, both before and after that Return, bear nothing of the Force which it reflects; Conſequently, the Weights will bear more or leſs in the Tranſit, by how much the more or leſs they are check'd in the Swing. But indeed, the Suppoſition is not to be allow'd; for in this, as in all Pendula, the Return is not made by any check of the Medium, on which they hang, but by their own Weight, riſing contrary to their natural Tendency: Nor is this of any Conſideration in the preſent Caſe; for, not to be too tedious in Particulars, ſuppoſe, (which ought not to be granted) that the Weights bear leſs in their Riſe, that will be compenſated by the Fall preciſely, if they ſwing equally; and if not, the Falls of an Increaſing Motion will compenſate the Riſe in the Decreaſing, and contrariwiſe. But the ſecond Caſe is much more conſiderable than the former, and difficult to be rightly and clearly Stated, that is, The Tendency from the Center, which is more or leſs, as the tranſverſe Impulſe is, and this according to the uncertain Rolling of the Ship. But neither will this be of any Moment, becauſe by how much the tranſverſe Impulſe of a ſwinging Weight is increas'd, ſo much the ſimple Gravitation is leſſen'd; which, for brevity I ſay, will need no other Demonſtration, than this eaſy Experiment of an ordinary Pair of Scales equipollent; Let the Fulciment be fix'd, and one Scale ſwing pendulouſly, while the other is at reſt, and it will appear, the Moving Scale will not over-balance the Reſting one.

Secondly, IT may be objected, That the Lids themſelves will be of ſome weight, and that muſt have the ſame Conſideration, as a Weight immediately fix'd to the Lid. Then I anſwer, (the Solution is very eaſy) Let the Lids themſelves be otherwiſe preponderate. But,

Thirdly, THE laſt Objection is much more material, which is this, Will not the Wind, ſearching into every Corner of the Machine, unequally, hinder or interrupt the exit of the evacuated Air, both at the Vents and the utmoſt Out-lets? which, if it do, will make the Preſſure, and conſequently the Motion of the Machine unequal. I anſwer, This may be prevented two Ways; firſt, Let every Receiver diſtinctly, be incloſ'd in a Caſe of fine Lawn, ſtretch'd on each ſide, thro' this let the evacuated Air gently ſile, ſo as that when the Wind ſearcheth on one ſide, the Air may have free paſſage on the other. It muſt be of an extent anſwerable to the whole Capacity of both the Out-let and the Vent, to give it a free paſſage without any ſtreſs; and cover alſo both Ends, the Top and Bottom, that the Siling in on one ſide may be not only anſwer'd at the other, but over-balanc'd by the Ends, Top or Bottom. This muſt needs break the Force of the external Blaſts, before it reach the Vent; becauſe every ſmall Interſtice of the Threads is a ſingle Inlet or Out-let, ſo narrow, that a Blaſt thro' it, would require the Force of an inconceiveable and impoſſible Hurricane to reach a very little Way, if it do not burſt the Linen. To demonſtrate which, it muſt be noted, That Attrition takes place in Fluids, as well as Solids; and is, in proportion to the compaſs of the Duct, a mighty Impediment to their Motion, where the Fluid paſſeth in ſuch a Quantity, that the external Parts of it, which ſuffer the Attrition moſt, ſerve by their Rotation, concurring Motion, or Fluidity, as a glabrous Conduit for the internal, their Force is conſiderable; otherwiſe not. However, we find by Experiment in Water, that a narrow Out-let does diſproportionably brace the paſſing Fluid, more than a wider. Now, I confeſs, that this is of Conſideration in the paſſage of the evacuated Air, as well as the intruding; but yet if the Caſes be large enough, the gentle Motion of the one in compariſon of the Violence of the other, makes the Ratio of both different; and in other Caſes, a free Paſſage without any ſtreſs, and conſequently, the equal preſſure of the Artificial Wind, may, by the largeneſs of the Caſes, be ſufficiently provided for, and therefore perhaps Tin Caſes pierc'd, or double Caſes might do better; for theſe and ſuch-like Reaſons, great Care muſt be uſed about the utmoſt Out-let, where the Sails are, that the Wind be not hinder'd or reverted there. Conſequently, at this Paſſage, as well as the reſt, the Air ſhould be empty'd into a Receiver, like thoſe above deſcrib'd. Secondly, The Force of the external Air, which blows ſide-ways, may be prevented by covering all the Receivers with one common ſolid Caſe, open only at the Bottom, or otherwiſe by a ſupernumerary Pair of Sails at the Out-let of the laſt Receiver; or Laſtly, By conducting the extravaſated Air thro' a Labyrinth, communicating with the free Air at every Turn, except one or two next the Inmoſt Receſs.

Fourthly, IT may be objected, That the Lids, when they Riſe, muſt require for that Motion a greater preſſure, than the Fall. I anſwer, That the Riſe and Fall will compenſate each other, and therefore the Motion in whole will be equal, for any the longeſt Period aſſign'd within the very inconſiderable Inequality of one Riſe or Fall, when their Number is unequal. Thus much for adjuſting the Power.

NEXT we are to Conſider the Structure of the Movement, which muſt be the equal Meaſure of Time; for which it muſt be noted, That tho' the Motion of the Sails, which are conſtantly the ſame, will be anſwerable to the weights of the Lids; ſo that by altering of theſe, it may be made more or leſs, and brought to any Standard, anſwerable to the Difference betwixt the Capacity of the Force-Pipe and the out-moſt Out-let, yet it will be a very difficult Matter to adjuſt this Power to the common Diviſion of Time, *i. e.* to Meaſure out Hours and Minutes preciſely for any aſſign'd Period; becauſe, if at ſeveral Eſſays, the Weights be increas'd or diminiſh'd, till the Motion be brought as near the

Standard, as our Senſes can determine or diſcern it for one Hour, or for twenty-four Hours, or a longer Period, (which by the way, will require more Care and Pains, than the generality of Workmen will take about it when the Thing comes into common Uſe) yet if there remain after all this Care, the leaſt Difference, ever ſo inſenſible for that Time, betwixt equal Time and the Index, that Difference will be continually multiply'd, as often as the given Period is contain'd in the continuance of the Motion, and riſe at laſt to a conſiderable Quantity. Beſide the abſolute Weight annex'd to the Lids of the Receivers, will be ſo very ſmall in proportion to the Velocity of the Sails, that the Differences of Weight, to be added or ſubtracted, will be a very nice Matter, and hard to be determin'd exactly: For this Reaſon, it will be better to proportion the Parts at Adventure, and then carefully to try, what the Effect will be, for a ſufficient Time together, that is, for the Time of a pretty long Voyage.

THIS Tryal muſt be made at Land by a good Pendulum-Clock, rectify'd as is above directed. Then the Revolution of any Part, being determin'd for any aſſign'd Period, there is no room to queſtion, but the Motion will be always equal; ſo that by the Rules of Proportion, any longer Period may be hereby truly Meaſur'd. Upon this Conſideration, this Contrivance is propos'd, rather as a Regulator to the common Movements, than as an Index to the ordinary Diviſions of Time: But yet it may ſerve alſo for this Purpoſe, under the foregoing Caution. Now as for the Movement itſelf, it is an indifferent Matter, in what Form it is, provided the Parts be ſo contriv'd and put together, that the Motion be equally divided, and thoſe Diviſions accommodated to Periods both large and ſmall; ſo that the Number of the ſmalleſt Diviſions may be Indicate for a ſufficient Period, *i. e.* the Duration of the longeſt Voyages: To which End, it is not abſolutely neceſſary, that any one Revolution in the Movement be of ſo long Continuance, provided that ſome one of the Indices do meaſure out a Period, whoſe Repetitions are eaſily remember'd, or otherwiſe accounted for; that is, a Day, a Week, or a Month. A Piece of Clock-work, of the ordinary Make, will ſerve very well, and the more ſimple and uniform it is, the better; particularly, Let the proportion of all the Pinions to their Wheels be the ſame throughout. As for Inſtance, Suppoſe it be Decuple, each Pinion driving a Wheel of ten Times its Circumference, then let the Axis of every Wheel, beſide that of the Sails, come through the Dial-Plate, and be furniſh'd with an Index, turning within a graduated Circle, Decimally divided, and number'd; in this Order, every Index makes ten Revolutions for one of the following, and every Figure numbers the Revolutions of the foregoing Index, by which Means every the leaſt neceſſary and ſenſible diſtinct Part of Time is indicated, and its proper Number, for any aſſign'd Period, given by Inſpection: For every Index anſwers to every Decimal Place of Figures, the firſt and ſwifteſt to Units, the ſecond to Tens, the third to Hundreds, *&c.* ſo that the Account of the whole Motion, to the leaſt Diviſion, may be taken by barely ſetting down the Numbers, as they occur in the Indices, obſerving the ſame Order, as is that of the Movement, beginning with Units.

THE next Enquiry to be made, is this, What Inequality will the Movement itſelf be liable to? I anſwer, The ſame as an ordinary Pendulum-Watch, with this advantageous Difference, that in one they may, and in the other cannot be accounted for, which are theſe three; the firſt ariſeth from the Variation of the Weather; the ſecond from the Irregularity of the Work; the third from the Coagulating of the Oyl. As for the firſt, The different Temper of the Air, hath a great Effect upon the Watch, which is always anſwerable to the Size of the Balance, and the frequency of its Vibrations; but in the Movement here deſcrib'd, the ſwifteſt Mover is progreſſive, not returning, as the Balance of a common Watch, and therefore does not allow the ſmalleſt Diſadvantage of the leaſt Pauſe, for this Inequality: Beſide, the Rapidity of the Motion will be an Advantage on our ſide; for all Ineptitude to Motion hath the greateſt Effect upon ſlow Movers; therefore this Variation will be but ſmall at moſt, and the Power being always equal, the difference of Motion will be more eaſily diſcern'd, and reducible to Rule. Further, Since the Power is the ſwifteſt Mover, this Inequality in the following Train will decreaſe every Step in a ten-fold Proportion, whereas in other Movements, where the Power is the ſloweſt, they increaſe in a like Proportion. Now by the Thermometer the Alterations of the Air are nicely Determinable, to which the anſwerable Variations may be eſtimated, a Rule being firſt ſtated by Experiment. Then, Secondly, As for the Irregularity of the Workmanſhip, if it be not very obvious, and very much, I may ſay, without any abatement, that it will be next to nothing, if the Wheels do not bear upon each other with any other preſſure, than that of their own Weight; which, Thirdly, ſufficiently obviates any Objections that may riſe from the laſt Cauſe mention'd, *viz.* The Coagulating of the Oyl. However, the Wheels may be made of Ivory, or any other ſuch like Matter, which will need no

Oyl, and yet ſerve every whit as well, as thoſe that are made of Braſs.

The Uſe of this Inſtrument take as follows: Let the Movement be try'd at Land, and a Table made of its Motion, accounted by its anſwerable Numbers; for all the common Diviſions of Time, *viz.* an Hour, a Day, or a Month; then at the Time of Departure let the Motion begin at any known Number, then at the Inſtant of Obſervation take down the Numbers pointed at by the Indices in their Order, beginning with the Number of the ſwifteſt, which ſet in the Place of Units, the next in that of Tens, and ſo on: The whole Number, conſiſting of theſe Particulars, gives the Motion of the Engine from the Time of Departure; which divide by that Number in the Table, which anſwers to any common Diviſion of Time, as an Hour, a Day, *&c.* the Quotient is the Number of Hours, Days, *&c.* from the Time of Departure, by which a Watch may be Corrected.

Hitherto the Enquiry has proceeded upon Movements, that will equally and alike ſerve both at Sea and at Land. The next Step, I ſhall take is to examine farther, Whether there may not be ſome Advantage for accompliſhing our Purpoſe, peculiar to this unſtable Element, within which the preſent Theory is confin'd. To this End, let us conſider, What makes the Difference; and what the Difficulty of Meaſuring Time more in the former than the latter? The Cauſe is obvious, and the very propos'd Terms of the Queſtion points out the Anſwer; It is the Inſtability of it. Its Motion renders it moſt repugnant to a regular Movement; if ſo, then let us make the beſt of our Lot, and try, whether we cannot turn Difficulties to Advantage. It is a Singularity in our Caſe, that two ſuch amicable Aſſociates, as Time and Motion, ſhould be irreconcileable; while Motion is the Meaſure of Time, and Time is the Meaſure of Motion, it is ſtrange, if we can make no Index of Time out of this Motion. However, it ſhall not paſs without a Speculation, eſpecially, when this Objection has ſtruck out of the Sea-man's Inventory one of the fineſt, and beſt improv'd Inſtruments in the World, that is, the Pendulum Clock; an Inſtrument ſo ſerviceable, nay, I may ſay neceſſary, in Practice of his Profeſſion, which if he wants much longer, I ſhall want my chief Wiſh (in Things of this kind) and ſuffer the far greater Diſappointment. It is no Argument of a wavering and unreſolv'd Mind, that I dwell ſo much upon the Pendulum, and that I attempt to preſcribe a Rule, where Irregularity prevails with uncertain Violence and Tyranny; but yet the Ocean is not without Law, and as the Laws of Nature were firſt ſettled with a gracious Regard to Humane Exigencies and Conveniency, ſo they furniſh us with an entertaining and uſeful Subject of Speculation in the exerciſe of that Reaſon, by which our MAKER teacheth us more than the Fowls of Heaven; and yet theſe, we ſee, can ſecurely tranſport themſelves from one Shore to another, over a vaſt Reach of the Liquid Waſte, without Pilot or Compaſs: This is to us a ſoliciting Motive to try the Power of Mechaniſm in the ſame Expedition, which in their Oeconomy we ſee ſo ſucceſsful, and never to reſt in ſupine Neglect, till we have either compaſs'd our End, or practis'd all poſſible Means thereto conducing. When we come cloſely to think on the Subject, we find another Paradox in this Problem, The Motion of the Pendulum is undulous, the Undulation of the Ship is in a ſort pendulous; and yet theſe two uniform Cauſes, are not yet brought to harmonize in the ſame Effect: This concordant Diſcord, is an urgent Provocation to one reſolute Eſſay upon the Subject, either to accompliſh our Deſign, or to ſee where it ſticks. Which I ſhall attempt in the following.

I KNOW, that the Propoſal I am going to make, would bear an Apology with ſome ſort of Criticks; but if the Thing in itſelf appear Reaſonable, it needs no other Vindication; and if not, I neither deſerve nor deſire any. However, I think it fair to warn the curſory Reader, that a few of the following Pages will but miſpend his Time, unleſs he can make Paſtime of a ſeeming Extravagancy, or elſe engage his Attention in the Search of Truth to the moſt minute and neglected Phænomena, without Prejudice or Impatience; and therefore, that I may either divert or inform him, I ſhall propoſe this Expedient in the plaineſt and freeſt Manner, without any artificial Diſguiſe, or other Embelliſhment than this, That here the Cart is ſet before the Horſe; that is,

A PENDULUM might be made to drive the Clock at Sea, as the Clock is made to drive the pendulum at Land. The only Poſtulate I require to Demonſtrate this, is, That a Ship under Sail will keep a free Pendulum in Motion: If this will not be allow d me, I might have recourſe to a ſufficient and approv'd Expedient for my Purpoſe in the Sequel; but I hope it will not be refus'd, if it be conſider'd, Whether a Pendulum could be born by the Hand any requir'd Length, ſo even and ſteady, as not to admit the leaſt Vibration; I am confident and poſitive it cannot: Then, if the Art of Man cannot do this, the unconſtant Force of the Wind, which drives the Veſſel, is leſs likely to effect it. Now, ſuppoſing the Vibration to be conſtant,

ſtant, while the Veſſel moves, though it be ever ſo ſmall, it is ſufficient, as by the following Deſcription of the Machine, I hope to make appear.

THE Pendulum muſt be fix'd to a ſtrong tranſverſe Axis, carefully fitted at each End to two Sockets, in which the Axis muſt Turn, that ſo the Pendulum may ſwing directly forward and backward, in the ſame Plane, and not in an Horizontal Circle; for the hanging of this Marine Pendulum, is not requir'd to be ſo nice and critical, as that of a fix'd Clock at Land, becauſe it is the firſt Mover, or that to which the Power is immediately apply'd, and this Power, *viz.* the Rolling or Pitching of the Ship, being very ſtrong and violent, the bearing of the Axis is in reſpect to its continuance very inconſiderable; whereas in the other Sort of Movements, the Power being at a great diſtance from the Pendulum, and communicating with it by a long Train, and its Force at every Step diminiſh'd in a large proportion, the firſt being the ſloweſt Mover, it has a very ſmall Effect upon the laſt, whoſe Poſition therefore requires a great deal of Care and Nicety, which in our Caſe will be inſignificant. Beſide the Inequalities, which may ariſe from the mention'd Cauſe, which is conſtant and invariable in an unconſtant and variable Motion, with others from a like Cauſe, are fully accounted for and indicated below.

THE whole Machine muſt conſiſt of a double Movement, or two diſtinct Parts, both of them driven by the ſame Pendulum, and both together being the Index of Time, the firſt ſhewing the Number of the Pendulum's Vibrations, the other the Length of them; both which are neceſſary to the right Meaſure of Time; becauſe, as was noted above, the reſiſtance of Air, to which I may add here alſo the bracing or bearing of the Center of Oſcillation, deſtroys the Equilibrium in a Pendulum, which varies its Arch, *i. e.* makes ſometimes a larger, and ſometimes a leſſer Swing; becauſe this Reſiſtance is always proportionable to the Arch, whereas the Laws of a free Pendulum, in itſelf conſider'd, require, as has been obſerv'd, that every Return be made in the ſame Time, whether the Swing be larger or leſs, and conſequently, the largeſt Sweep is ſwifteſt; therefore ſuffers the more Reſiſtance, which (I ſaid) is proportionable to its Arch; ſo that this Pendulum, which varies its Motion much more than thoſe of any other Movements, according to the uncertain Motion of the Ship, muſt be liable to much greater Inequalities, which in the Courſe of a long Voyage will riſe to a conſiderable Article, and muſt have its proper Index, diſtinct from that which gives the number of its Vibrations, *i. e.* we muſt have two independant Movements, wrought by the ſame Pendulum, which I ſhall proceed to deſcribe ſeverally.

It is an indifferent Matter, whether theſe two be compacted into one Frame, or no; whether they be plac'd on the ſame ſide the Pendulum, or no, provided their Motion (and Parts) do not communicate. However, I ſhall ſuppoſe in the following Deſcription, (to avoid Confuſion) that they lie one on this ſide, the other on that.

The firſt Part is that, which ſhews the Time by the Number of the Swings, this muſt communicate with the Pendulum by a ſmall oblong Piece of Iron or Braſs, fix'd at one End of the Axis perpendicular to it, or parallel to the Shank of the Pendulum, but above it (to avoid Accidents) this I ſhall call the Tricker, this will vibrate with the Pendulum in a concentrick Arch. Round the End of the Tricker muſt be a Braſs Circle, or rather Semi-circle, having the ſame Center with that of the Tricker's Oſcillation, and ſomewhat wider than the Arch, deſcrib'd by the Vibration of its Extremity; this I ſhall call the Balance, becauſe it is deſign'd to obey the Pendulum, and therefore may be ſupported, but not fix'd to the Axis of the Pendulum, as well as a proper Axis of its own; nay, if it could be brac'd tight enough upon it, would ſcarely need a Tricker; but the bearing on an Axis, has but a ſmall proportion of Strength to the Force at the Circumference; ſo that to ſecure it there is no truſting to this alone.

THE inner Circumference of this Balance muſt be wrought ſmooth, upon which the Tricker muſt bear pretty ſtrongly by a Spring faſten'd to the End of it. The Vibration of the Balance muſt be but very ſmall, that it may equally play its utmoſt Range by every the leaſt ſhake of the Pendulum, and no more by the largeſt Sweep; being gag'd by two fix'd Stops at each End. The next Wheel driven by the Balance, will be the firſt progreſſive Mover of the Watch-part, and have a double Indenture, the Diviſions of which muſt be preciſely equal to the Vibration of the Balance-Wheel. The Work of this Wheel muſt be like that of the common Crown-Wheels, except that the Teeth muſt be much ſmaller, and therefore more numerous. The ſloping edge of each Tooth, lying at a very acute Angle with the intended Courſe of the Wheel, and the other edge perpendicular to the Circumference, as alſo that the contrary Side of its Circumference muſt be indented in like manner, having its Teeth equal in Number and Size with the former, but looking the contrary way: This Wheel muſt communicate with the Balance by a ſmall Catch, fix'd to the latter, of a very pliant, but durable Spring, gently gliding over the ſloping edge of every Tooth in the Vibration, but ſtopping upon the perpendicular Edge, ſo as to drive it a Step forward in its Return: On the contrary Side muſt be a ſecond Catch, like the former, fix'd to ſome immoveable Part of the Frame, ſtopping the Return of the Wheel with the Balance upon the other Indenture. The reſt of the Work muſt be like that of common plain Watches, and furniſh'd with proper Indices upon the Dial-Plate, as above deſcrib'd.

THE ſecond Movement on the other Side of the Pendulum, which I call the Regulating Part, becauſe it ſerves to adjuſt the Account of Time given by the former, will differ but very little from it; muſt have a Tricker, as above deſcrib'd, but no Balance, the firſt progreſſive Mover being driven by the Tricker immediately, with a Catch fix'd to it inſtead of the Spring in the former Part; this I ſhall call the Pendulum-Wheel, becauſe it immediately communicates with it. It muſt ply exactly to the Motion of the Tricker, and have two contrary Orders of Indenture, but the Diviſion as ſmall as they can be made; and therefore each Order ſhould rather be tripple, or quadruple, and the Wheel (for this Purpoſe) as large as Conveniency will allow, that every Point of the Pendulum's Return, ſenſibly diſtinct, may have a different Catch; but leſt this ſhould not be plain enough, I muſt be more particular: My meaning then is, That there ſhould be three or four Rows of Teeth, like thoſe of a Saw round the inner Circumference of the Pendulum-Wheel, a-like in Number, Size and Form, all looking the ſame way, and the croſs Ranges of the Teeth, reckon'd a-thawrt each Circular Order, ſhould lie diagonally, or oblique to the Courſe of the Wheel; ſo that the correſponding Diviſions of each Circle of Teeth, may be intermediate to each other, and as many Catches, fix'd upon the end of the Tricker, as there are Rows or Circles of Teeth round the Wheel, falling in their Turns at equal Diſtances of Time, as they run over the Teeth. Thus alſo the outer and convex Circumference of the Wheel muſt be fitted and furniſh'd with a triple or quadruple Row of Teeth, in all reſpects like the former, as ſmall as can conveniently be made, but looking contrary ways. To each Row muſt be fitted ſo many Catches, as before deſcrib'd, but fix'd to ſome immoveable Part of the Frame to prevent the Wheels returning with the Tricker. It is to be noted in this Deſcription of the Parts, that theſe two belonging to each Movement ſeverally, which are driven by the Pendulum, *i. e.* the Balance in the Watch-Part, and the Pendulum-Wheel in the Regulating Part, are deſign'd to be hollow, for their reſpective Trickers to play freely within their concave Circumference; which implies, that their Radii or Spokes, ſupporting their Circumference, are fix'd to the outer Edge of their Rim, and that this Rim is of a conſiderable breadth, like an Hoop hanging over their Trickers. The Pendulum-Wheel alſo muſt drive a diſtinct Movement, like the other. I need not be particular in a farther Deſcription of the Movements ſeverally; for the plainer they are the better; only obſerve by the Way, that neither of them can be conveniently fitted to the common Diviſion of Time, becauſe neither the Number, nor Length of the Swings will be conſtantly the ſame, and therefore the Decimal Diviſion of the Indices, above-mention'd, will be beſt, becauſe both the Notation, and Uſe of the Numbers in the Method propos'd, will be very ready, and not liable to lead a Perſon into Miſtakes by a credulous Dependance on one part, which a ſupine Obſerver would be often apt to content himſelf with, if the Hours and Minutes were given by Inſpection, eſpecially when the Movement and his Obſervations be often found to coincide.

What hath been ſaid of the Form and Deſign of the Parts, will be ſufficient Direction in the Size and other material Circumſtances of them, particularly, the Length of the Pendulum, though it is indifferent, yet ſhould be made pretty near the common Length, that it may ſwing Seconds. The Weight or Bob of the Pendulum muſt be pretty heavy, and therefore the Shank muſt be very ſtrong, and its Juncture to the Axis very firm. The length of the Tricker muſt not unreaſonably exceed the Compaſs of the Frame, but with this Caution, The longer the better. The Place of the Movement muſt not be near the Center of the Ship's Gravity, becauſe there, (if the Point could be found preciſely) the different Poſture of the Ship turning upon that point invariably, would leave the Pendulum at reſt: for nothing but the Motion of its Center, (upon which it hangs) can ſwing the Pendulum, which is otherwiſe free; ſo that nothing, but the unequal progreſſive Motion of the Ship would be left for the Purpoſe; whereas it will need ſometimes the Advantage of its Rolling and Pitching for a conſtant Motion, which Conſideration does direct us to the true Poſture of the Frame, which ſhould neither be preciſely Direct, nor Tranſverſe to the Courſe of the Ship, but oblique, for thus the Pendulum will have this double Advantage, That when the Ship inclines, either ſide-ways, or end-ways, the Pendulum will obey it.

HERE alſo it is neceſſary to obſerve, That when the Pendulum ſweeps more than a Semi-circle, it loſeth of its Regularity; for to a Pendulum, that hath a ſolid inflexible Shank, there are two Points of Reſt, both in the Perpendicular-Line, with the Center of Oſcillation, one above, and the other below it, diametrically oppoſite to each other. Now if to each of theſe we aſſign a Semi-circle, then it is obvious by Inſpection, that in the upper the Weight tends from the Reſting-point, in the other to it, in both with a Force and Velocity more or leſs anſwerable, though not alike proportionable to its Diſtance from the Point of Reſt, in the ſame Range, while it traverſeth it; conſequently, in the upper Semi-circle the Velocity about the Point of Return approacheth to the Point of Reſt, and yet the whole Range is thereby increas'd; and therefore the Time which the whole Swing takes, when it riſeth to more than a Semi-circle, is hereby increas'd; ſo that though the Velocity in the under Semi-circle is ſomewhat increas'd thereby, yet this Increaſe being not proportionable to the Decreaſe in the other (as is evident, if we conſider that the Velocity in the whole Deſcent increaſeth about the Proportion of Deſcending Bodies according to the Verſed Sine of the Arch it deſcribes in either of the Semi-circles) the whole Time of the Vibration, more than a Semi-circle, muſt diſproportionably increaſe, more than the exceſs; and therefore it muſt be ſome way or other prevented from Ranging more than a Semi-circle.

BUT it will be objected, That there is no need of this, ſince the Rolling of the Ship cannot exceed a Semi-circle, without over-ſetting. I anſwer, But yet if the waving of the Ship backward and forward, chance to precede and equal the Vibration of the Pendulum, it muſt needs increaſe it; which needs no other Demonſtration than this obvious Experiment; A free Pendulum, or a Weight hung in a String, may be turn'd quite round, with a very ſmall Motion of the Hand, humouring the Swing, and this too with great Violence and Rapidity. Now I own, that this is a very great Chance, but yet all Caſualty, whether likely, or unlikely, ſhould be provided for.

ON the other hand it will be objected, That the wavings of the Ship, if they chance to equal and follow the Vibrations of the Pendulum, will quite ſtop it. I grant it; but then as ſoon as it has ceas'd, which (if the ſame Motion continue) will be but a very ſmall Moment, that very Motion will give it a new Swing: And therefore, ſince the Movement is contriv'd to indicate the leaſt ſenſible Vibration, this very ſmall Interruption may be ſafely neglected; conſidering alſo, that Matter and Space being diviſible *in Infinitum*, and the two Motions muſt be equal to leſs than can be imagin'd, before the Vibrations ſtop, the Chance lies too far out of all Bounds of Reaſon to be fear'd.

AGAIN, it will be ſaid, If the Pendulum muſt have a Stop to a Semi-circle, why may it not within leſs than a Semi-circle be ſtop'd, to gage the Vibrations, and ſtint them to an Equality, that the Trouble and Expence of a ſecond Movement, to ſhew the Inequalities, may be ſav'd? To this, I anſwer, It is impoſſible to do this to any good Effect; becauſe, when the Ship lies (as often it will) very much inclining on one ſide, the Point of the Pendulum's Reſt, with reſpect to the invariable Poſture of the Frame, or the very ſmall Vibration of the Balance, is alter'd, and therefore if the Vibrations of the Pendulum be ſtinted invariably to the ſmalleſt Range, which ſometimes it will ſweep, (and if not, ſome Inequality will ſtill remain) on each ſide the Point of Reſt, in an upright Poſture, then in the inclining Poſture, which throws the Point of Reſt beyond the Stop, the Pendulum will lie fix'd upon the Stop, the uncertain Duration of which, makes all uncertain: Beſide, if the Pendulum be thrown with any Violence againſt the Stop, the Vibrations will be anſwerable to the Rebound, without any regard to the Length of the Pendulum; and if the Stop be made of any Matter that will hinder a violent Rebound, then the Pendulum will conform to the Rolling of the Ship, or elſe to the Elaſticity of the Stop. Therefore we muſt not think of any Stop or Gage upon the Pendulum within leſs than a Semi-circle, which, notwithſtanding the foregoing Conſiderations, may be allow'd, ſince the Perpendicular of the Pendulum cannot in this Caſe exceed, or be thrown beyond the Stop, nor can this rebound more than once, though the Veſſel ſhould lie along upon the Surface of the Water, which ſeldom happens.

THINGS being diſpos'd in this Order; Next let us conſider the Effect: And firſt, The Balance will vibrate as oft as the Pendulum, becauſe the Spring upon the End of the Pendulum bears harder upon the Balance, than any Thing elſe is ſuppos'd, and therefore will carry it along with it. Secondly, The Pendulum hath free Scope to ſweep its utmoſt Range within a Semi-circle, having no direct Hindrance, but the Stops above-mention'd, which it will ſeldom reach; for the concave Circumference of the Balance, upon which it bears, being wrought ſmooth, the Spring of the Tricker will eaſily ſlide upon it. Thirdly, The Vibrations of the Balance are numbred by the Balance-Wheel, which moves a Step forward for every other Swing of the Pendulum ; ſo that for every ſtep of the Wheel two ſwings muſt be allow'd : Therefore, if this Wheel carries an Index, and the Pendulum ſwings Seconds, then the Horary Diviſion of the Dial-Plate is thus ; Of the firſt Circle into 30, for the Revolution of one Minute ; the next into 60, for an Hour ; the next into 24, for a Day ; the following, into 10, *&c.* the Train being broken and forecaſt accordingly. But the Decimal Diviſion of the Dial-Plate, is thus ; Of the firſt Circle into 5, or 50 ; the ſecond, and all the reſt, into 10, the Pinions and Wheels being proportion'd accordingly : But if the Pendulum ſwings half Seconds, which is leſs convenient,then the Horary Diviſion of the firſt Circle is into 60 ; the Decimal Diviſion into 10 ; Of the reſt as above. Fourthly, By the other Tricker, which ſweeps an Arch, equal to that of the Pendulum, and catcheth immediately upon the firſt Wheel of the ſecond Mover, in every Point of Return, drives the Wheel along with it, conſequently, this Part will move faſter or ſlower in any aſſign'd Time, according as the Pendulum rangeth a larger, or a leſs Length. The Indices of this Movement cannot conveniently be other than Decimal, wherein the foregoing Directions are to be obſerv'd ; ſo that the Motion of the one, compar'd with that of the other, will ſhew, what Allowances are to be made for the Inequalities hence ariſing, as by the following Article.

THE Rules for the Uſe of this Inſtrument are to be adjuſted by the Length of the Pendulum principally, not without Regard to ſome other material Conſiderations, which will occur by Experiment.

THUS far I have Conſider'd the Meaſure of Time by Regular Movements or Pieces of Clock-work, as either Adjuſted or Corrected. But there are other Meaſures of Time more promiſing, becauſe more ſimple, and liable to fewer Accidents, or Uncertainties, and thoſe more eaſily accounted for, or prevented, which therefore deſerve a Conſideration in this Place; but becauſe all, that I can at preſent foreſee upon this Article, are founded upon the ſame Principles, I ſhall recommend but one particular Expedient of this kind, as a Specimen of that Indulgence, which Nature (exerciſeth or) ſheweth to Indigent Mortals, in accommodations ſubſervient to their Convenience, Neceſſity or Satisfaction, that is the Air Pump, which might be ſo contrived as to meaſure Time equally. To demonſtrate this I ſhall begin with a deſcription of the Engine its ſelf, the Form and Diſpoſition of its Parts, ſerving our preſent purpoſe.

LET there be provided a Large Sphæroidical Veſſel, of a convenient ſize, as ſuppoſe a Yard in Diameter, of a very ſtrong Mettle, ſuppoſe Copper, $\frac{1}{3}$ or $\frac{1}{2}$ an Inch thick, ſufficient to bear the force of the utmoſt preſſure, and external accidents. At the bottom of this Veſſel let there be an Hole 2 Inches wide or more, let this Hole be inſerted into an Air Pump of the common make, (which therefore I need not particularly deſcribe) and cloſe Sodered. At the ſide of the Veſſel muſt be a very ſmall Inlet, as ſmall as it is poſſible to be made, by which the Veſſel muſt fill, and therefore it will require ſome Care in the making, and enquiry in this Deſcription, to prevent Accidents. If the Inlet be of Metal, it will be apt to ruſt, and be choaked up, and therefore it ſhould be made of Matter, that will not change, yet ſtrong and durable. On this account I believe Agate is the propereſt; in the working of which, that the Inlet may be ſtrong, and yet ſmall enough, let the Piece be firſt made flat, then with a Drill, having a very fine Point, wrought into a pretty acute Angle, let this Piece of Agate be pierced almoſt through, but not quite, then let the contrary ſide be gradually wrought down, till the Hole juſt begin to appear, then with a very fine Point of a proper Inſtrument let the ſmaller end of this Hole be finiſhed carefully, that it be not ſenſibly widened, and yet that no Splinters of the former Work may remain, leſt the force of the tranſient Air break them off, and render the Experiment uncertain. This Inlet ſhould be in the ſhape of a Funnel, to admit a Stopple carefully fitted to it, if occaſion require. Then let the Agate be cloſe inſerted into the ſide of the Veſſel, with its wider Orifice outward; at the top of the Veſſel there muſt be a Vent, half an Inch wide, or more. The outſide of the Veſſel, about the Vent, muſt be ground, or otherwiſe wrought plain, very fine, and furniſhed with a Lid, Poliſhed as the other, falling Perpendicular on the Vent, and cloſe Covering, but not much exceeding it. This Lid ſhould be pretty ſtrongly drawn back with a Spring, faſtned to a Stile or Cock erected over the Hole; again the Spring, when it flies, ſhould report by a Warning, (*viz.*) a Bell, a Muſical String or a Whiſtle: This laſt ſeems the fitteſt, and therefore I ſhall deſcribe it. Let there be a Leather Veſſel of a Cylindrical form, and ſufficient capacity, and cloſe made up, extending almoſt the whole reach of the Spring, having for its Bottom a round piece of Wood, and for its top a ſmall Tin Whiſtle, of a ſhrill Note, like that, which Children call a Swallow Whiſtle; Let this be faſtned at one end to the

Lid of the Vent, at the other to the Cock or Stile, to which the Spring plies, that the Spring may, when it comes, preſs the Wind out of the little Bellows thro' the Whiſtle; but yet ſo, as that the preſſure may not begin, till the Lid has quit the Hole a little way, leſt the ruſhing in of the Air, (of which by and by) ſhould force back the Lid, and by the frequency of this Accident batter and damage the Vent. Round the Place of the Warning lid, ſhould be 3 or 4 little Stays, Studs, or elſe a Ring, as near the Lid when it is down, as conveniently may be, not to bear upon or brace it in the leaſt. This will prevent the Lids ſhoving off the Vent by any ſhocks ſide-ways, which otherwiſe might eaſily be, by Reaſon of the ſmoothneſs of its Poliſh.

THE Deſign of this Structure of Parts is obvious, That by the Air-pump the Veſſel is to be empty'd of all its Air, and by the Inlet to fill again; which, it being made very ſmall, will take up a conſiderable Time. As ſoon as the Veſſel is near full ſooner or later, according to the ſtrength of its Spring, (but always at a certainty, or at an equal diſtance of Time from the Moment of its being totally exhauſted) the Warning is ſuppos'd to fly; for when the Veſſel is empty, the Vent and Out-let being cloſe ſhut, the Preſſure of the Air on all ſides of it will be almoſt inconceivably ſtrong, ſo as not only to ruſh thro' the Inlet with an impetuous Violence, but alſo to hold faſt the Lid, which therefore neither needs, nor ſhould have any other Tenure; but when the Veſſel has imbib'd a ſufficient quantity of Air, the preſſure of the internal and external will become equal; and therefore before that Time, the Spring, which is ſuppos'd to be pretty ſtrong, will exert itſelf, and as ſoon as its Draught over-balanceth that of the Veſſel, it opens the Vent by pulling away the Lid, and gives the Call.

By this Means a certain Period of Time may be duly Meaſur'd a Ship-board, and a Watch thereby rectify'd, *i. e.* ſince the the Inſtrument will ſhew, when that Period is compleat, it will ſhew thereby, whether the Watch hath gain'd or loſt of equal Time; and the ſame Experiment being repeated continually, as oft, and as long, as Occaſion requires, will unqueſtionably (to my Apprehenſion) duly Meaſure the Time of the longeſt Voyage, by which the Difference in apparent Time betwixt the Place of Departure, and the Place of Obſervation, being found, their Difference of Longitude is diſcover'd alſo.

The Sufficiency of this Expedient, will beſt appear, by examining particularly, What Inequalities it may be liable to in the following Queries?

Query I. Whether the different Temper or Denſity of the Air will not diſpoſe it to a quicker Paſſage at one Time than at another, ſo as that the Veſſel may not always require an equal Time to fill? I anſwer, Though it is unqueſtionably true, that the Air is denſer at one Time than at another, yet ſince the Paſſage and the Veſſel are always the ſame, they will always be alike proportionable; ſo that if the Capacity of the Inlet admits more Air when condens'd, than when rarify'd; ſo anſwerably doth the Capacity of the Veſſel, and that in a proportion exactly the ſame, as any One will find, if he will make the Calculation upon any given Dimenſions of the Inlet and the Veſſel; therefore the Time of the Veſſel's filling will always be the ſame, any Thing in this Objection notwithſtanding.

Quer. II. WHETHER the Air may not be differently lubricous or liquid, and therefore diſpos'd to a quicker paſſage at one Time, than at another? I anſwer, That the Fluidity or Lubricity of the Air can be of no moment in this Place, under any other Conſideration, than as it contributes to the Spring or Preſſure, and hereby alſo it becomes more denſe or rare, and belongs to the foregoing Query, which has been anſwer'd: For the Paſſage of Air will always be anſwerable to the Draught, and this always to the Standard or Quantity of Air imbib'd; the Inlet will be always alike lubricous; and therefore, ſuppoſing that the Air is not ſo, yet it's plain to a Demonſtration, that the ſwiftneſs of its Paſſage depending upon this Cauſe, muſt be anſwerable, either to the eaſy gliding of the Particles of the Air by each other, or by the Orifice of the Inlet. Now the latter of theſe two Caſes, admits of no Variety, becauſe the Inlet is ſuppos'd to be more perfectly glabrous, than the Air can poſſibly be; and when two Bodies ſlide upon each other, the Motion is always anſwerable to the Lenity of that which is moſt apt to Motion; for if the one be perfectly ſmooth, the other hath no Inequalities in the ſurface thereof to catch upon, or retard its Motion, every Thing elſe being equal, and in both Caſes the chief Impediment of Motion, is the Preſſure of the external Air, crouding into the Inlet, which is always anſwerable to the Draught.

Quer. III. WHETHER the Valve or Turn-cock at the bottom of the Veſſel, next the Force-pipe, excluding the exhauſted Air, as alſo the Stopple of the Inlet, and the Warning-ſhut can be made to ply ſo cloſe as not to admit the leaſt Draught of Air, till the Computations begin? I anſwer, It is indeed poſſible, but not without greater Care in the Workmanſhip, than the Buyer ſhould ſecurely depend upon, if ſuch Inſtruments come into common Uſe; but the Deſign of them may be fully anſwer'd, without ſuch Nicety; for whatever Vents the Veſſel may have, while they continue always the ſame, the Time of its filling will be the ſame from the Moment of the laſt Draught by the Air-pump, whence the Computation ſhould begin.

Quer. IV. Whether the Weather, or other uncertain Cauſe may not influence the Warning-Spring, ſo as to make it draw with unequal Force, and fly at different Degrees of the internal Draught? I anſwer, This is a Conſideration why it ſhould be made pretty ſtrong, and draw with near its utmoſt force; for it ſeems, that the weaker the Spring is, the more obnoxious it will be, becauſe a laxer Tenure gives it more Liberty: But yet thence it ſhould follow, that the Spring might be brought to ſuch a Temper and Strength, as would free it entirely of all ſuch Inequalities, or reduce them to an inconſiderable matter. Then as for other Cauſes, ſuch as the weakening of the Spring by a continual Stretch, Obſervation and Theory will eaſily account for any Inequalities, hence ariſing; wherein there will be this Conveniency, That the longer it is uſed, the leſs will be the Uncertainty. However, upon the whole of what has yet been offer'd, I may ſay with Confidence and Security, That all Varieties depending on the Weather, will be plainly indicated by the Thermometer and portable Barometer.

Query V. WHETHER the Force of the Wind will not contribute to fill the Veſſel faſter? I anſwer, The ſame Solution will ſerve to this, as to former Objections; that is, The Veſſel muſt needs fill according to the Draught, which no external Force can accelerate; for the Draught is inconceivably ſtronger, than that the paſſage of the Ingredient Air can equal it, and therefore the Air will ruſh into it with the utmoſt Force poſſible, which no Blaſt can equal, nor therefore increaſe. Beſide, we find by conſtant Experiment, that no Blaſt of Wind will enter into a Veſſel that hath but one Vent, except ſo much as the width of the Paſſage, or the elaſticity of the included Air, gives an advantage to; and this Argument holds in the preſent Caſe againſt an overpluſs, as much as if the Veſſel was perfectly full: And for the Exception in the former Caſe, there is no room in the latter.

Query VI. WHETHER the Draught be abſolutely and always alike? Since what we conceive under that Notion, is no more than the Preſſure or Weight o the Atmoſphere, which by the Barometer appears to be unequal? I confeſs, this is the Principal Objection, to which all the reſt are but Trifles, but neither will this overthrow the Deſign, I am fully perſuaded upon the following Conſiderations.

1. THE Velocity of the Tranſient Air does not ſeem wholly to depend on the preſſure of the Atmoſphere in this Caſe, but more upon its Fluidity; for the paſſage of the Air, though very ſwift and forcible, into the Veſſel entirely empty, or leſs full, than the Warning requires it to be, to me ſeems much leſs than the preſſure of the Atmoſphere

ſphere would effect upon any other capable Subject, *i. e.* the Effect ſeems not adequate to the Power of the Cauſe, in the loweſt Degree of Vigor or Efficacy, and therefore this will act to the utmoſt of what the recipient Property of the Subject, (that is, its Fluidity) and the Diſpoſition of Materials admits, both which have been already prov'd to have a conſtant Effect.

2. WHATEVER encreaſeth the preſſure, and makes the Motion ſwifter, can have no ill Effect upon our Inſtrument; becauſe it muſt anſwerably make the Air lie cloſer in all Places, that have free Communication with the Atmoſphere; and therefore if in the contracted Atmoſphere the ſame quantity of Air lies in a leſs room, ſo it will be in our leſſer Sphere, and conſequently the faſter it fills, the more it will require, and the Time (for any Thing in the Objection) will be the ſame. To make this Article plainer, I would rather chuſe to argue in the vulgar Terms, and upon the common receiv'd Notion of Attraction, ſince Nature by ſuch Conceptions leads us uſually the readieſt way to a Concluſion. In this way of Thinking, it will eaſily ſuggeſt, that the Barometer will not draw the Mercury ſo ſwiftly and forcibly to the Station of 28 Inches, when it has no further to go, as to 31: and that the diſtance makes amends for the ſwiftneſs or ſlowneſs of its Progreſs: So on the other hand, though this Argument may at the firſt View ſeem to make againſt us, yet it is as much on our ſide, as we can deſire; for there is more Air imbibed, or the Veſſel receives more, when the Motion is ſwifter, than when ſlower, and the Time is the ſame.

3. SUPPOSING the unequal preſſure of the Atmoſphere may occaſion any Inequality in the

Time of the Veſſel's filling, yet the portable Barometer gives Advantage enough to eſtimate and correct this Inequality.

HOWEVER, upon the whole of this Matter, putting all theſe Objections together, we may ſafely conclude, That if it be as poſſible, as it is improbable, that this Inſtrument be liable to any Irregularities, yet the Repetition of the Experiment muſt either correct, or reduce them ſo low, that in long Voyages, where the Longitude is moſt wanted, it muſt needs be of great Uſe; becauſe the Inequalities proceeding from the Cauſes mention'd, or any other, do not multiply but compenſate each other, but may be ſufficiently diſcern'd and accounted for by thoſe preparatory Experiments, which muſt determine the Time of the Veſſel's filling.

FOR the Uſe and Working of this Inſtrument, ſome Directions will be neceſſary. Particularly, the Time of the Veſſel's filling, muſt be exactly try'd at Land before it be uſed, by a good Pendulum-Clock, well rectify'd, as above is directed; and for greater Satisfaction, let the Experiment be repeated ſeveral Times in all Varieties of Weather, and the exact Time of its filling be ſet down or remember'd: Then in eſtimating the Motion of the Watch any Time after, this Rule will eaſily ſerve. So much as it exceeds or falls ſhort of this Time, while the Veſſel fills, ſo much it gains or loſeth of Equal Time in that Space, by obſerving which, a conſtant and exact Account of Time may be kept, during the longeſt Voyages; by which the Difference in apparent Time, betwixt the Place of Departure and any aſſign'd Station, may be found, to which their Difference of Longitude is anſwerable. In ſettling the Account great Care and Diligence ſhould be uſed: Indeed it ought to be one Perſon's whole Buſineſs to attend it, eſpecially conſidering the great Advantage of finding the Longitude, and that no other Buſineſs of the Voyage, in ordinary (ſetting aſide Accidents and Hazards) can be more neceſſary; and it very ſeldom happens, that all Hands are aloft: Beſide, that it is the very Thing for which a conſtant Care and Attendance hath been hitherto uſed upon the Log-board throughout the longeſt Voyages.

In working this Inſtrument, obſerve, That all the Air be entirely exhauſted; to which End, let the Draught be repeated 2 or 3 times more, than otherwiſe may be thought neceſſary, to draw out every the leaſt breath of Air, for the greater Certainty and Satisfaction; but yet, conſidering the unmeaſurable elaſticity of the Air, a certain number of Draughts ſhould be made; and all this, as near as may be in the ſame Time; eſpecially, if the Inlet be left open, while the Draught laſts, which, unleſs the Veſſel be very ſecure from any other Vent, I ſhould rather adviſe, otherwiſe there ſhould be a ſmall Plugg or Stopple nicely fitted to the outer and wider Orifice of the Inlet, which being done, and all other Parts anſwerably ſecure, then let the Computation begin from the removing of the Stopple; but if not, from the Moment of the laſt Draught, and end at the Warning; that is, Let the Perſon, who preſides over this Buſineſs, obſerve exactly by the Watch, the Hour, Minute and Second there given at the Moment the Veſſel begins to fill, and alſo at the Moment when the Warning flies, noting it in an Account, kept for the Purpoſe, every Turn.

In exhauſting the Veſſel, obſerve, That the Warning-ſhut be firſt clos'd, and not quitted till the Draught of the Air exceeds that of the Spring, and will hold it faſt; then at every return of the Rammer at both Ends of the Force-Pipe, let the Stop-cock be turn'd Quarterly, opening when it goes, and ſhutting when it comes; and this very exactly, both as to Space and Time.

THE ſmall Time which will be betwixt each Operation, that is, betwixt the Warning and the Recruit, will not need any other Meaſure, than that of the Watch, becauſe the Motion of this being adjuſted or corrected by the Inſtrument, what Allowance ſhould be made for the Intervals, will appear by the main Account; as alſo how long and how many thoſe Intervals are: In the Account, beſide Hours and Minutes, the Seconds ſhould have a Place, for theſe will, if frequent, make a conſiderable Article, by no means to be neglected; becauſe in the apparent Diurnal Revolution of the Heavens, four Minutes anſwer to a Degree of Longitude, and a few Fractions will amount to ſo much; ſo that by ſuch neglect, in the Courſe of a ſmall Voyage we ſhall have leſs Certainty, than even the mean Motion of the Moon will give, by which we may come within two or three Degrees of Truth; therefore the Seconds muſt not be omitted: And yet in the common Sort of Pocket-Watches we have no Index for Seconds. Now to ſupply this Inconvenience, the Peruſer muſt be very ready at beating Seconds in his Mind, which he may quickly attain by accuſtoming himſelf, a little now and then to the Trial by a Pendulum-Clock; or elſe, if this does not pleaſe, let him hold in his Hand a Plummet, of a due Length requir'd to ſwing Seconds, and by a gentle Motion of his Hand give it a ſmall Vibration, then count the Seconds thereby: In one or other of theſe Ways let the intermegence ſhould be uſed: Indeed it ought to be one Perſon's whole Buſineſs to attend it, eſpecially conſidering the great Advantage of finding the Longitude, and that no other Buſineſs of the Voyage, in ordinary (ſetting aſide Accidents and Hazards) can be more neceſſary; and it very ſeldom happens, that all Hands are aloft: Beſide, that it is the very Thing for which a conſtant Care and Attendance hath been hitherto uſed upon the Log-board throughout the longeſt Voyages.

IN working this Inſtrument, obſerve, That all the Air be entirely exhauſted; to which End, let the Draught be repeated 2 or 3 times more, than otherwiſe may be thought neceſſary, to draw out every the leaſt breath of Air, for the greater Certainty and Satisfaction; but yet, conſidering the unmeaſurable elaſticity of the Air, a certain number of Draughts ſhould be made; and all this, as near as may be in the ſame Time; eſpecially, if the Inlet be left open, while the Draught laſts, which, unleſs the Veſſel be very ſecure from any other Vent, I ſhould rather adviſe, otherwiſe there ſhould be a ſmall Plugg or Stopple nicely fitted to the outer and wider Orifice of the Inlet, which being done, and all other Parts anſwerably ſecure, then let the Computation begin from the removing of the Stopple; but if not, from the Moment of the laſt Draught, and end at the Warning; that is, Let the Perſon, who preſides over this Buſineſs, obſerve exactly by the Watch, the Hour, Minute and Second there given at the Moment the Veſſel begins to fill, and alſo at the Moment when the Warning flies, noting it in an Account, kept for the Purpoſe, every Turn.

IN exhauſting the Veſſel, obſerve, That the Warning-ſhut be firſt cloſ'd, and not quitted till the Draught of the Air exceeds that of the Spring, and will hold it faſt; then at every return of the Rammer at both Ends of the Force-Pipe, let the Stop-cock be turn'd Quarterly, opening when it goes, and ſhutting when it comes; and this very exactly, both as to Space and Time.

THE ſmall Time which will be betwixt each Operation, that is, betwixt the Warning and the Recruit, will not need any other Meaſure, than that of the Watch, becauſe the Motion of this being adjuſted or corrected by the Inſtrument, what Allowance ſhould be made for the Intervals, will appear by the main Account; as alſo how long and how many thoſe Intervals are: In the Account, beſide Hours and Minutes, the Seconds ſhould have a Place, for theſe will, if frequent, make a conſiderable Article, by no means to be neglected; becauſe in the apparent Diurnal Revolution of the Heavens, four Minutes anſwer to a Degree of Longitude, and a few Fractions will amount to ſo much; ſo that by ſuch neglect, in the Courſe of a ſmall Voyage we ſhall have leſs Certainty, than even the mean Motion of the Moon will give, by which we may come within two or three Degrees of Truth; therefore the Seconds muſt not be omitted: And yet in the common Sort of Pocket-Watches we have no Index for Seconds. Now to ſupply this Inconvenience, the Peruſer muſt be very ready at beating Seconds in his Mind, which he may quickly attain by accuſtoming himſelf, a little now and then to the Trial by a Pendulum-Clock; or elſe, if this does not pleaſe, let him hold in his Hand a Plummet, of a due Length requir'd to ſwing Seconds, and by a gentle Motion of his Hand give it a ſmall Vibration, then count the Seconds thereby: In one or other of theſe Ways let the intermediate Seconds be found (when the Index of the Watch in the Time of Obſervation, ſtands betwixt two Diviſions) betwixt the Index and the next Term; their Number, thus found, ſubtracted from 60, gives the Number of Seconds above the laſt foregoing Term, which with it is to be plac'd to Account.

If after all that hath been ſaid hitherto, there remain any ground of Scruple or Suſpicion of Uncertainty, two or more ſuch Inſtruments, ſet to any certain Proportion of Time reſpectively, and carefully attended, will, I think, obviate all Objections, and ſufficiently compenſate both the Trouble and Charge of them.

For further Satisfaction, it will be proper to find the Longitude, as often as Opportunity allows throughout the whole Courſe of the Voyage, in which, if Expedients anſwer their End, and the Run of the Ship come any thing near Expectation, by degrees, leſs Care and Trouble will become needful, than at the firſt.

To prevent Accidents, little need be ſaid more than in general, That the Inſtrument be guarded from violent Shocks, Bruiſes and Falls; that it be kept Clean, eſpecially about the Warning, that the Inlet be ſecur'd with a fine piece of Lawn, ſtretch'd before it, or otherwiſe, from Gnats, Motes, Duſt, or any Thing that might choak it up: However, that nothing get within the Veſſel, that might leſſen its Capacity. Thus much of the Inſtrument itſelf.

What further Directions are neceſſary in the Uſe of it, reſpects the Watch itſelf, whoſe Diviſions may be, and often are very unequal; therefore ſhould be carefully examin'd, before any Thing to a Certainty can be determin'd thereby, and its Inequalities adjuſted in Tables for that Purpoſe; the firſt to every Hour in the 12 or 24, according to its Continuance; the ſecond for every Minute in the Hour. Theſe Inequalities of the firſt Sort, are in the Fuſee; the ſecond, in the Diviſions of the Dial-Plate; for which Reaſon ſome Care ſhould be taken, that the Watch always proceed from the ſame Stop, or rather, that the Stop (upon the Fuſee) to the Winding up, be always kept to the ſame Hour and Minute. This will be better underſtood by an Example; Suppoſe a Watch, deſign'd for 24 Hours, have its full Continuance 28 (the overplus of 4 Hours being allow'd for Conveniency, that a ſmall delay of Winding it up, may be no loſs of Time) and that at 7 in the Morning it be wound up quite to the Stop, then, I ſay, the Stop is at 7, and that at 7 next Morning it has gone its full Courſe, though it be not quite down: Then, if at the ſame Time preciſely it be wound up again, and the Fuſee have ſo many Turns as are run off in 24 Hours, as ſuppoſe 6 (according to the common Make of Pendulum-Watches, now in Uſe) I ſay, the Stop is kept to the ſame Time; and not only in this Caſe, but if at any Time within the 4 laſt Hours the ſame Caution be obſerv'd, of giving it ſix Turns preciſely, the Stop is ſtill kept to the ſame Hour, that is, the Fuſee ſtands in the ſame Poſture, as if at that Hour preciſely the Watch had been wound up to the Stop, which for our Purpoſe is neceſſary, that the ſame Inequalities of the Fuſee may happen at the ſame Hour and Minute; which otherwiſe, cannot be aſcertain'd ſo conveniently.

Now, that it may have its juſt number of Rounds, obſerve, when you wind up, and the Key is put on, to clap your Thumb, or rather for exactneſs, the Edge of your Thumb, over-againſt the End of the Key, and after the propos'd number of Turns, bring the ſame End to the Edge of your Thumb, as before; or if it will not ſtay there, a thought farther, till you are ſure the Catch of the Wheel ſtays upon the ſame Notch of the Fuſee: With this Reſtriction, it is almoſt indifferent, at what Time of the four laſt Hours, that is, from 7 to 11, it is wound up; but yet the nearer 7, the more the Spring is kept upon the ſtretch, which in courſe of Time might weaken it; the later it is, the weaker is the Draught, and the more liable to Uncertainty, unleſs the Fuſee be nicely adjuſted throughout, and therefore 9, is the more convenient Hour.

HAVING now finiſh'd my Propoſal upon the former Part of this Complex Problem, I ſhould now proceed to the Method of finding the Hour of the Day or Night by the Altitude and Azimuth of the Heavenly Bodies, But becauſe this Subject is largely and ſufficiently Handled in other Treatiſes, every-where to be met with, I ſhall omit it.

I AM aware, it will be objected, That the Method of finding the Hour by the Heavens is very precarious, becauſe of the uncertainty of the Weather. To this, I anſwer, That the true Time of the Morning or Evening may be had within 4 or 5 Minutes, or leſs, in any Latitude, and in any Variety of Weather, without Clock, Watch, Dial, or any other Inſtrument, deſign'd for that Purpoſe, even though the Sun, Moon, or any of the Stars ſhould diſappear, during a whole Voyage, by the

Help of the following Note, *viz.* That Day-light will ſerve a good Eye to read a ſmall Print in very cloudy Weather, when the Sun is 7 Degrees below the Horizon; in clear Weather, when he is 9 Deg. and an half below the Horizon; but becauſe all Eyes are not of the ſame ſtrength, this Account is to be ſettled by Experiment, with the help of a good Pendulum-Clock, in all variety of Weather: Where obſerve, that in a great Variation in the Poſition and Opening of the Clouds, in the Sun's Quarter, will make but a ſmall Difference either in the Time of the Night and Morning, or the Altitude of the Sun: However, I have by Experience found it an eaſy Matter to eſtimate theſe. After I had taken a ſlight Survey of the Heavens, obſerving, how much of the clear Sky was viſible, and at what diſtance from the Horizon, and the Sun's Azimuth. Now when by frequent Experiments the Altitude of the Sun to the Antipodes has been calculated, and reduc'd to proper Tables, to every conſiderable variety of Appearances in the Atmoſphere, and theſe Experiments aſcertain'd by a good Pendulum-Clock at Land, in the open Air, and in Places where the Horizon is free, ſuch Tables will give by Inſpection the Sun's Altitude to the Antipodes at any Time after, and in all Places univerſally. If the preciſe Moment when the Letters of the Print (which ought always to be the ſame) diſappear to the naked Eye, or becomes inviſible by Day-light, be remark'd.

HERE Note, That the ſame Eye is not always alike diſpos'd; but to prevent all Uncertainty on this Account, let not the Perſon that makes the Obſervation, come near any Candle, or other Artificial Light, till the Obſervation be over; and I can by Experience aſſure him, that this Method of finding the Hour in the gloomieſt Weather, will ſerve to a conſiderably greater Nicety, than what I have yet ſpoken of, provided his Eyes be not diſtemper'd.

These Appearances of the Atmoſphere, which I here mention, are the Rarity or Frequency of the Clouds, or rather, the Opening of the clear Sky, which ought to be meaſur'd and eſtimated by the Degrees of the Sphære, and ſome Conſiderations had of their Diſtance from the Sun's Quarter, by which it is an eaſy Matter to judge what Differences in the Degrees of Light are hereby made, betwixt either of the Extreams. As for Example: An Opening of the clear Air, 16 Deg. Long, 4 Broad, and 10 above the Horizon, having the ſame Azimuth, as the Sun, gives a good Eye an Advantage of Reading by Day-light, till the Sun be about 8 Deg. $\frac{2}{3}$ below the Horizon.

By this Method alſo, the Latitude may be nearly determin'd, if two Obſervations daily be made, one at the Morning, and the other at the Evening, with an Allowance anſwerable to the Weather; as alſo the true Diſtance betwixt the Obſervations meaſur'd by the Pocket-Watch; and this even at Sea. For though the Veſſel may in that Time conſiderably alter its Latitude, yet at the ordinary Rate of Sailing, this will make but an inconſiderable Difference in the Length of Day, where our Trade moſt lies: Beſides, ſuch Obſervations are deſign'd to Determine the Latitude at the middle of the given Period.

Then, having thus found the Latitude, the Longitude will not be far to ſeek; for the Sun's Altitude being given at the Antipodes, their Hour is eaſily found, and that is the ſame with the Hour at the Station to be determin'd. Then the Difference of Longitude betwixt that and the Place of Departure is anſwerable to their Difference of Apparent Time.

THIS, I hope, will be ſufficient to ſatisfy the Publick of the Likelihood, or Poſſibility at leaſt, of Determining the Longitude by the Methods here propos'd; and all that, I think, will be neceſſary at preſent to be ſaid upon this Subject. If this proves acceptable, and Providence permits, I purpoſe to Communicate ſomething more, to facilitate the Practice of theſe Expedients, and to ſatisfy the Inquiſitive Reader of the Truth of theſe Obſervations. I had prepar'd more for the Preſs upon ſeveral of theſe Particulars; but finding, that it would ſwell the Book, and inhance the Price to more than would be readily allow'd, I forbear the mention of them.

FINIS.

ERRATA.

In the Dedication, Page 3. line 22. read *Precedents*. p. 3. l. 1. Book, read *Accuracy*. p. 43. line 29. *dele* Therefore.